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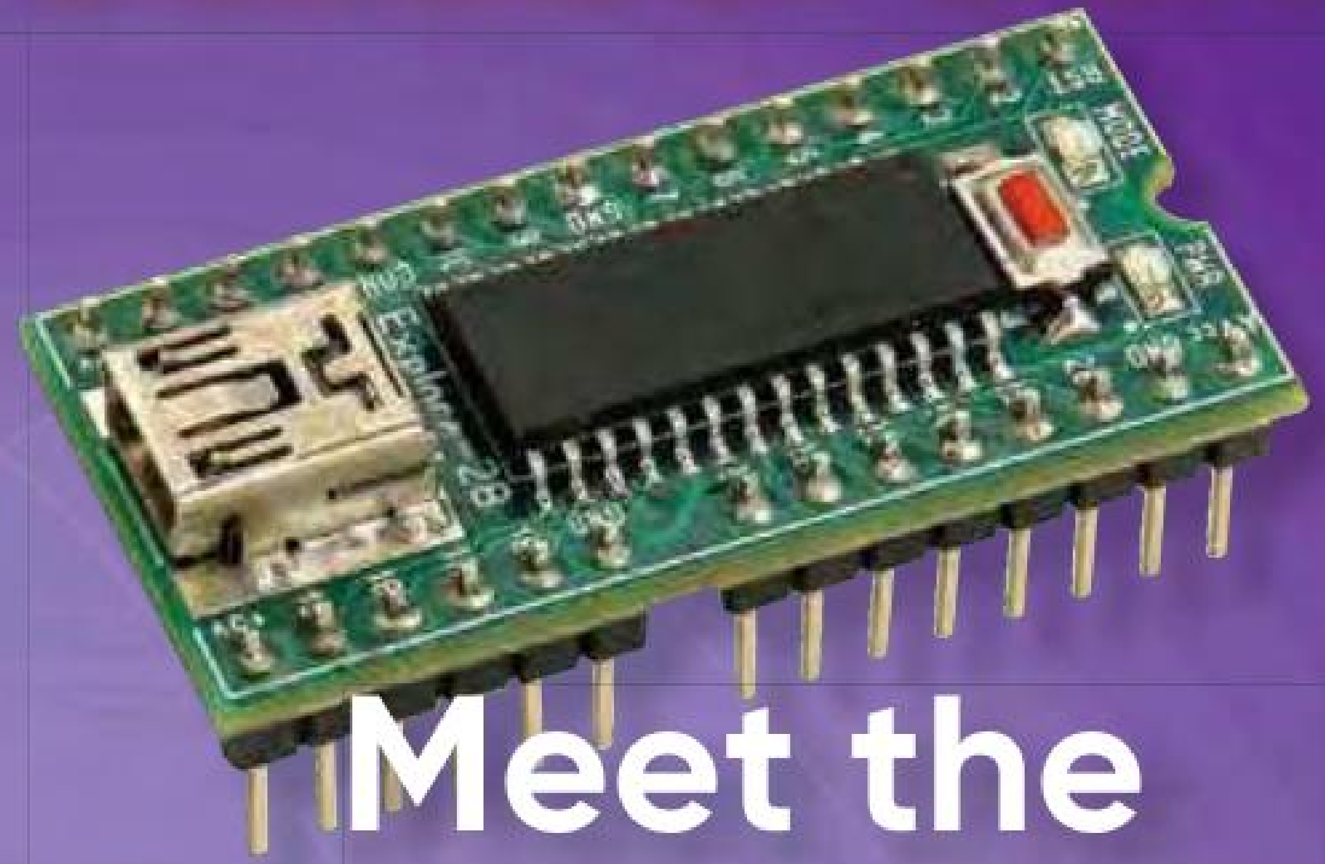

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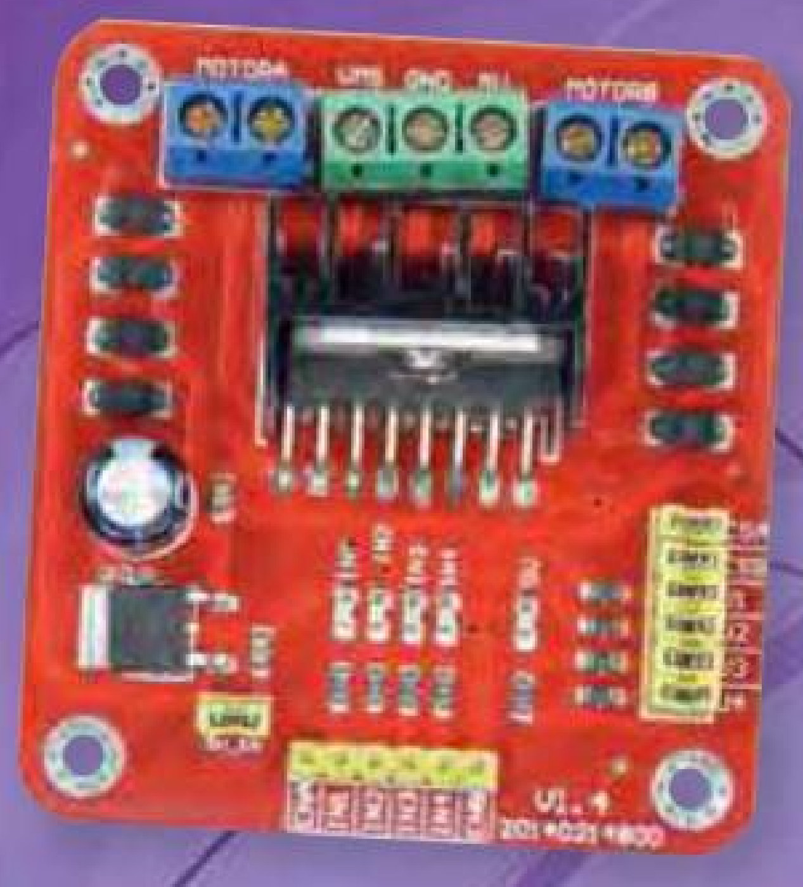

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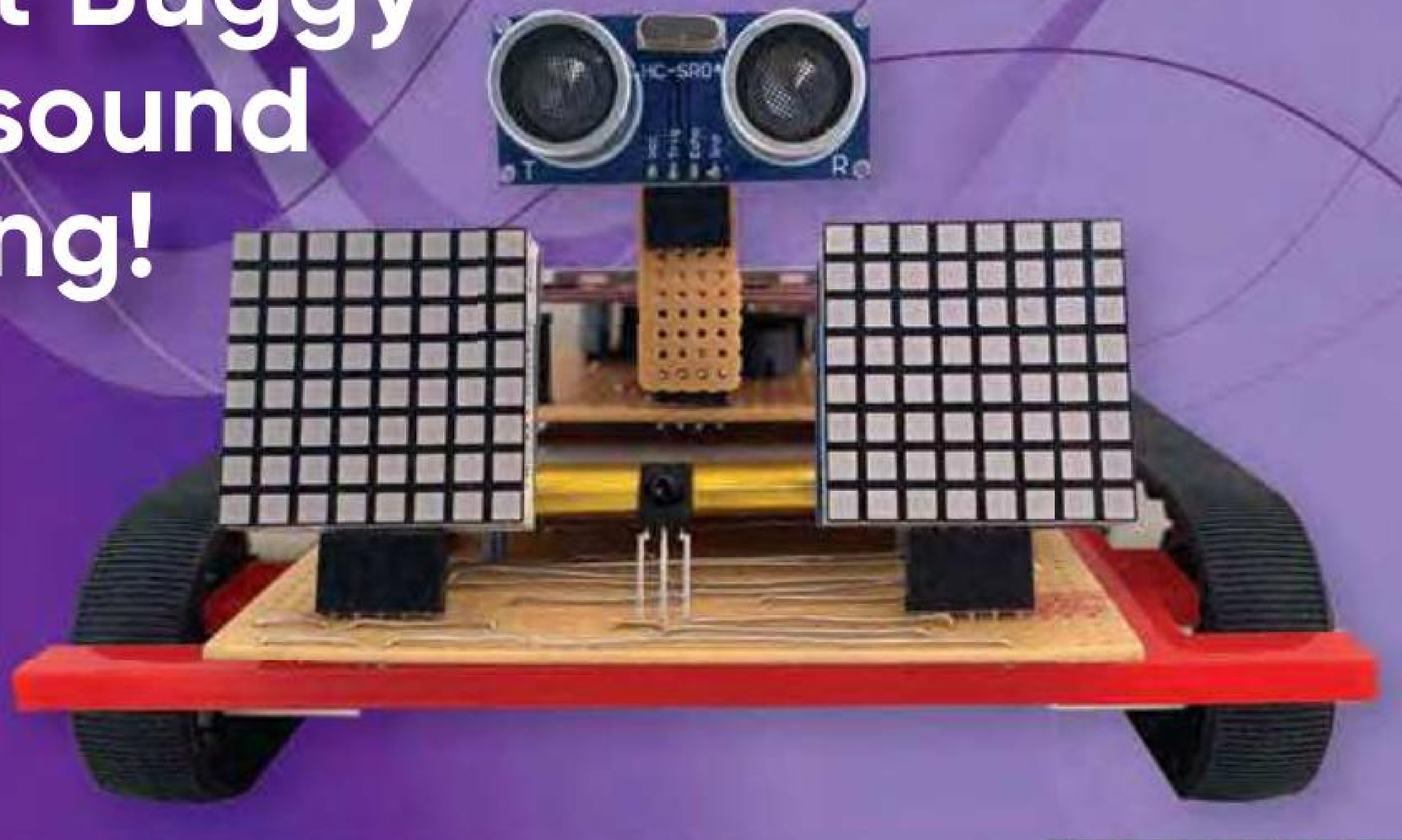

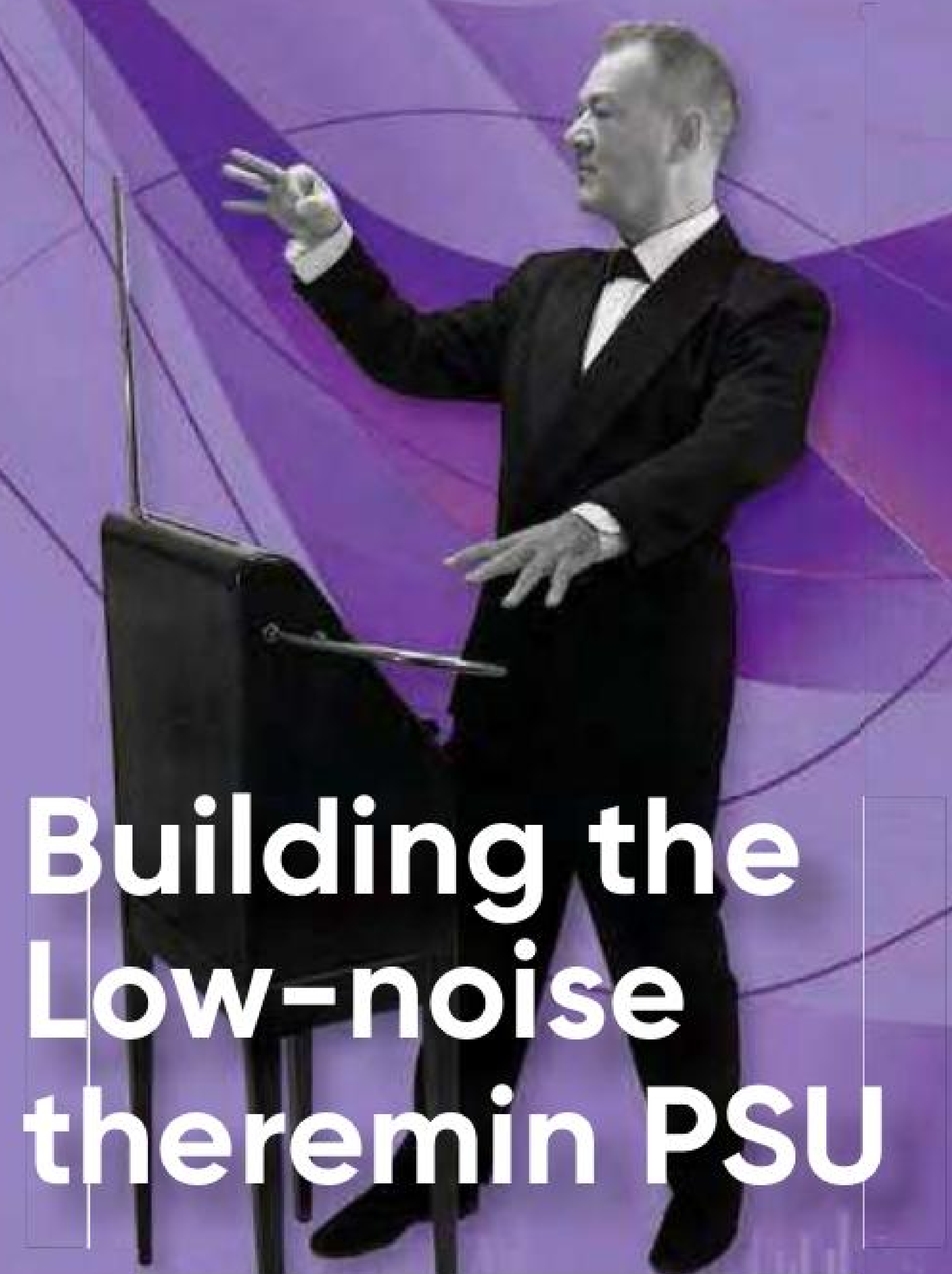

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Practical Electronics

Volume 49. No. 9
September 2020
ISSN 2632 573X

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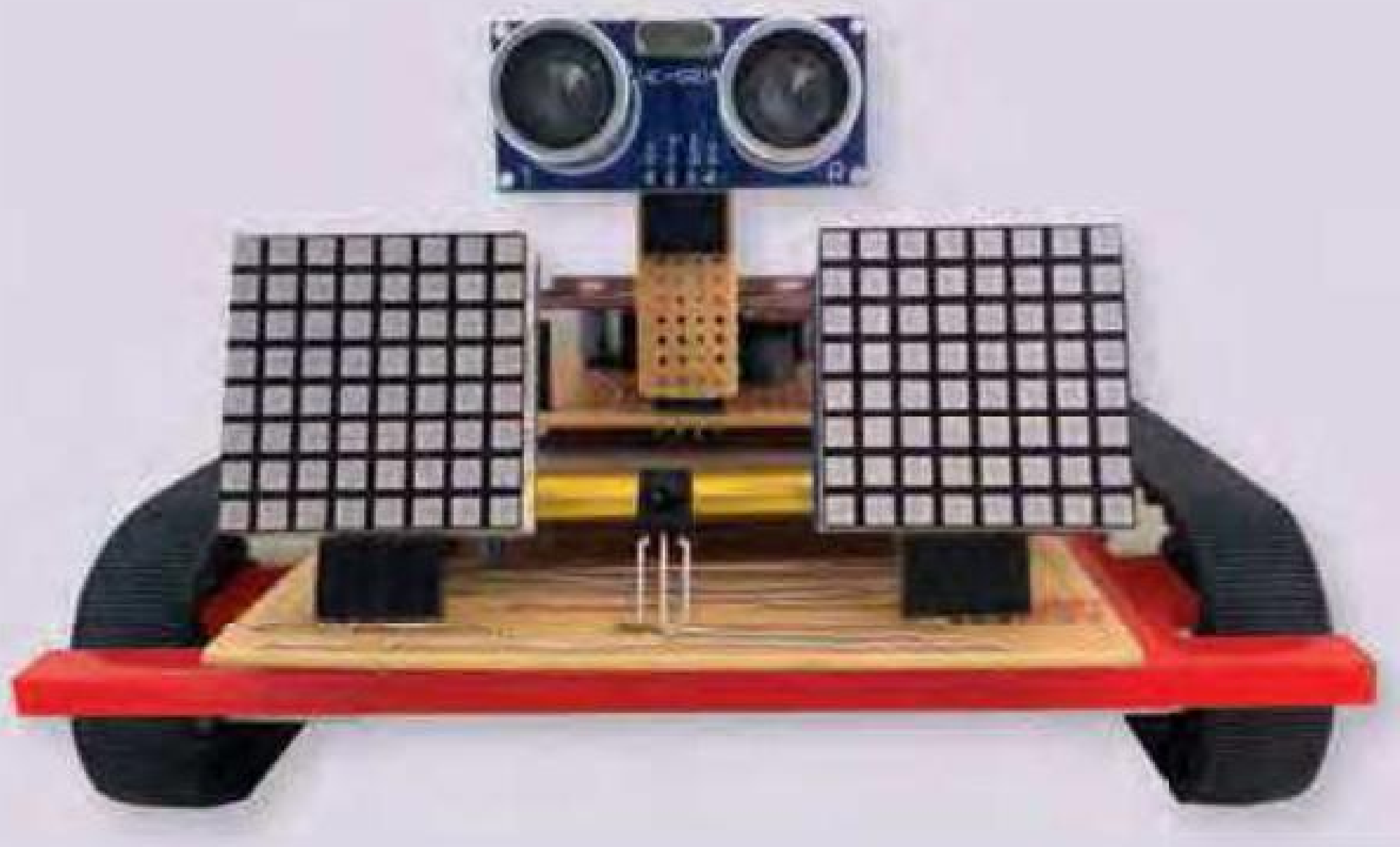

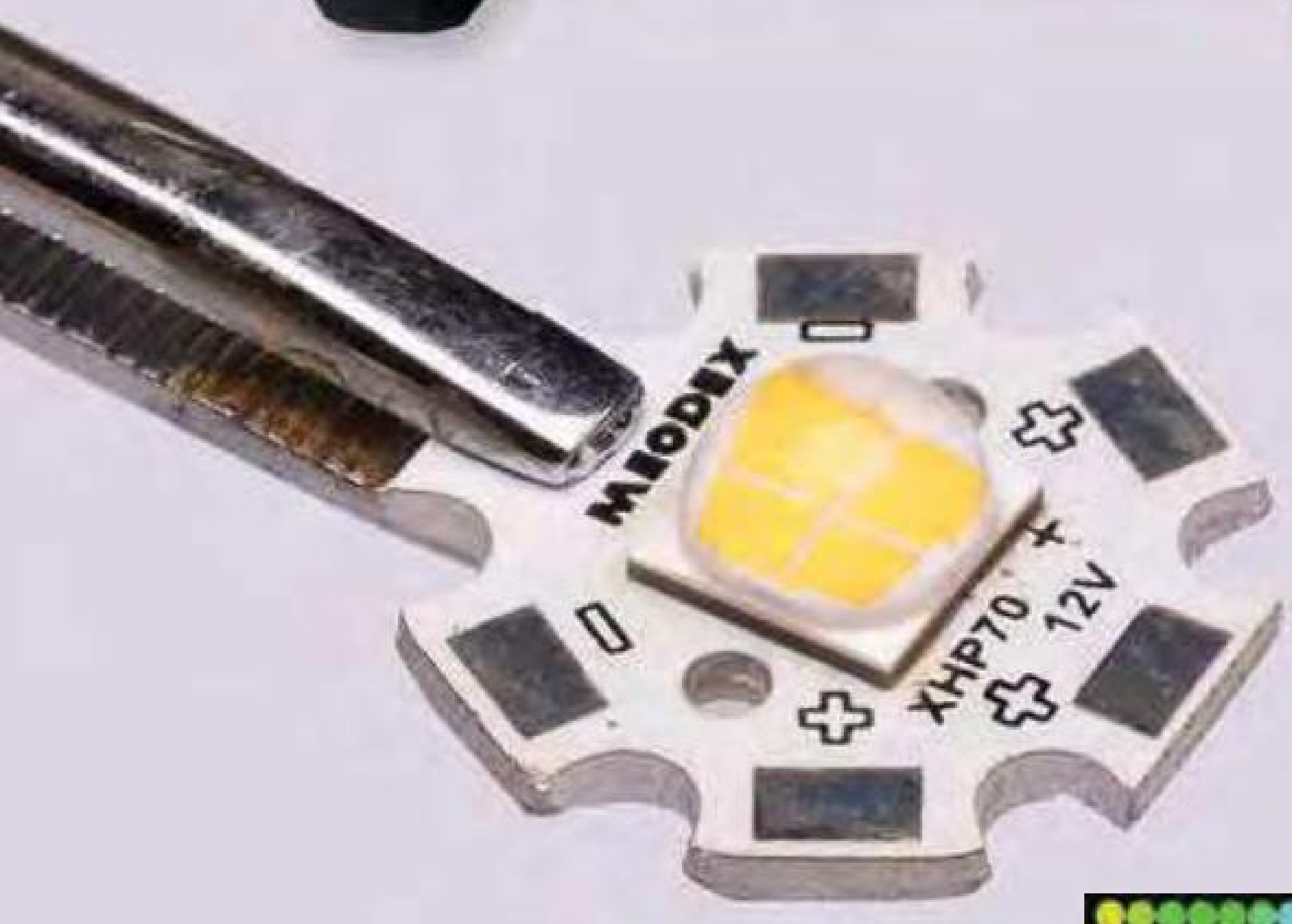

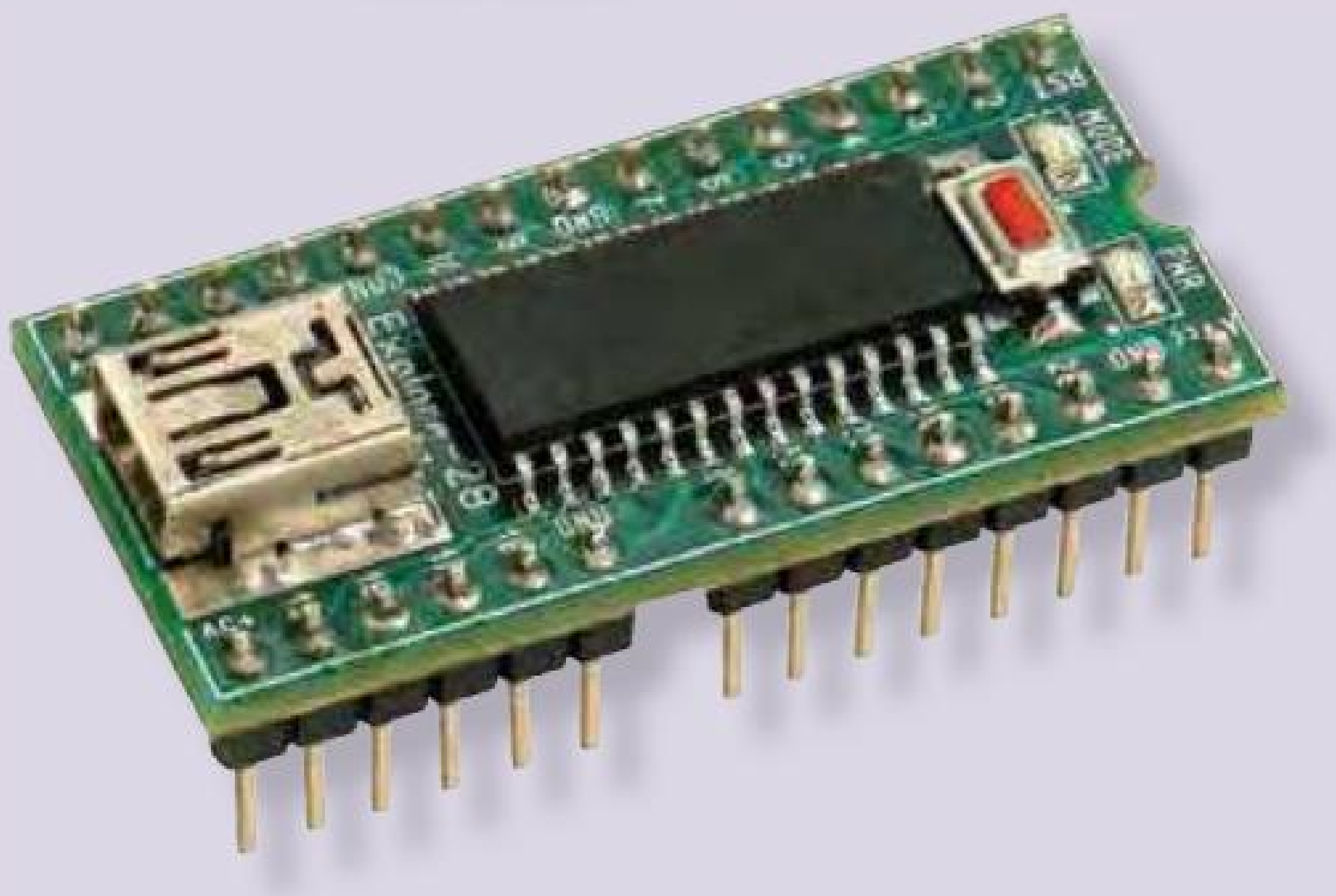

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WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

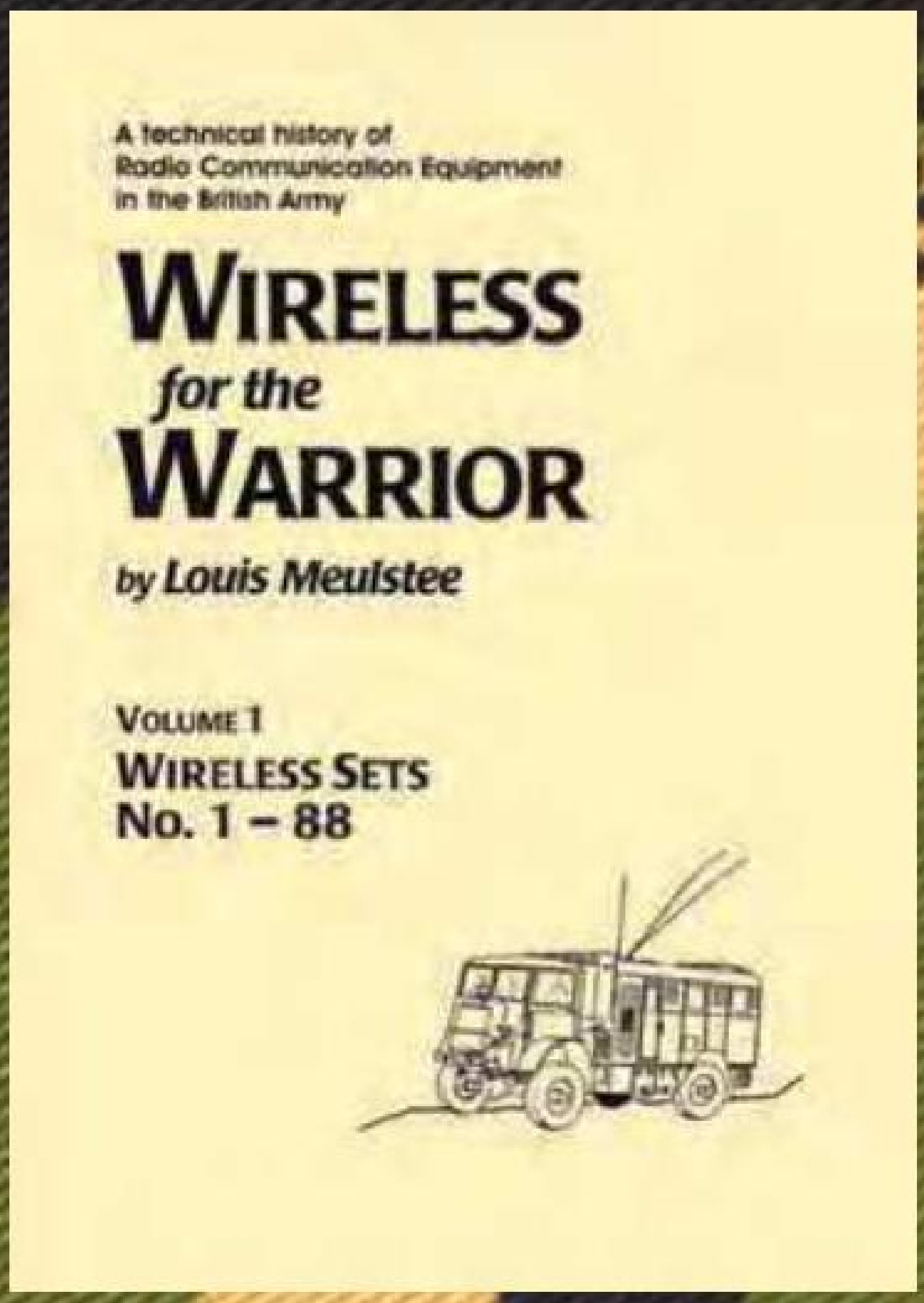
The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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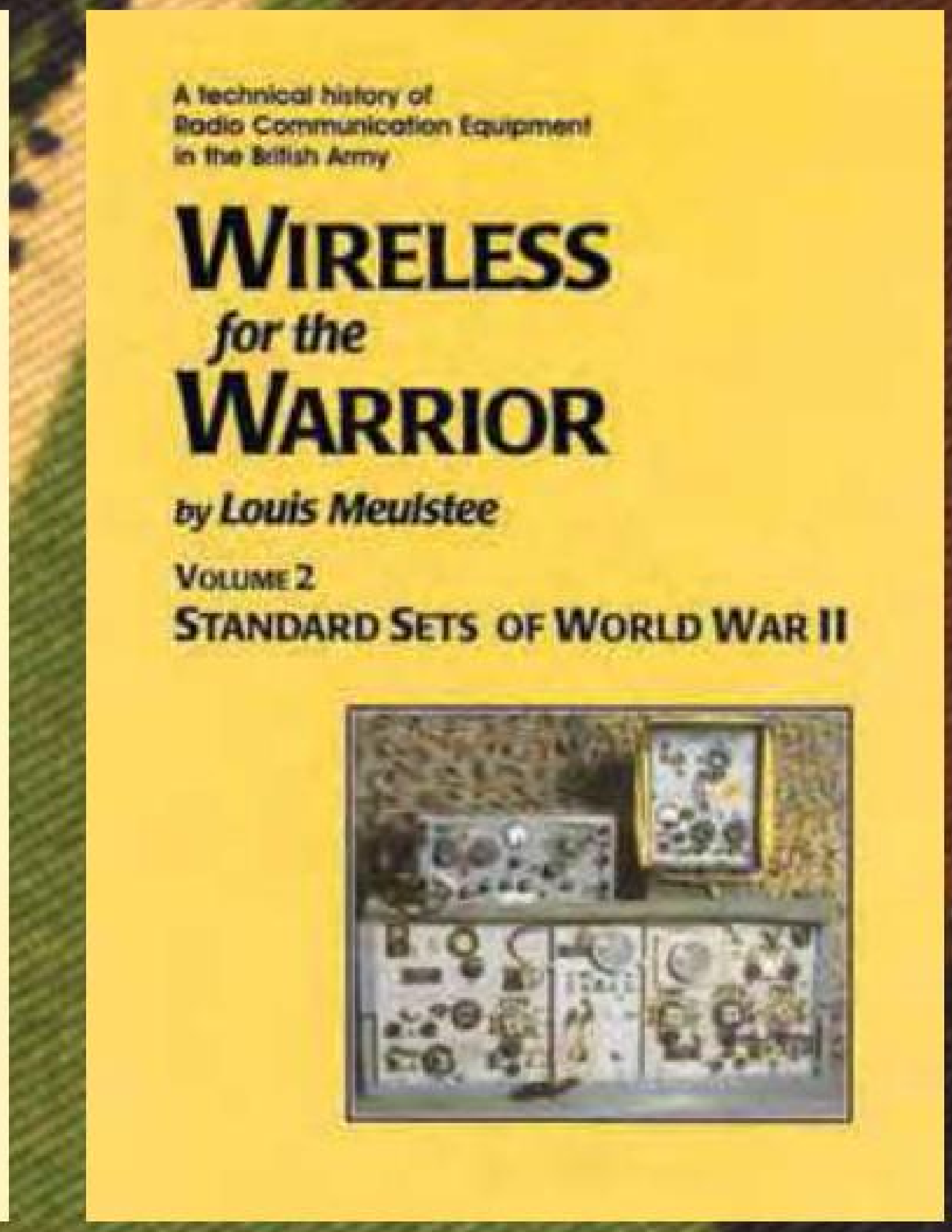

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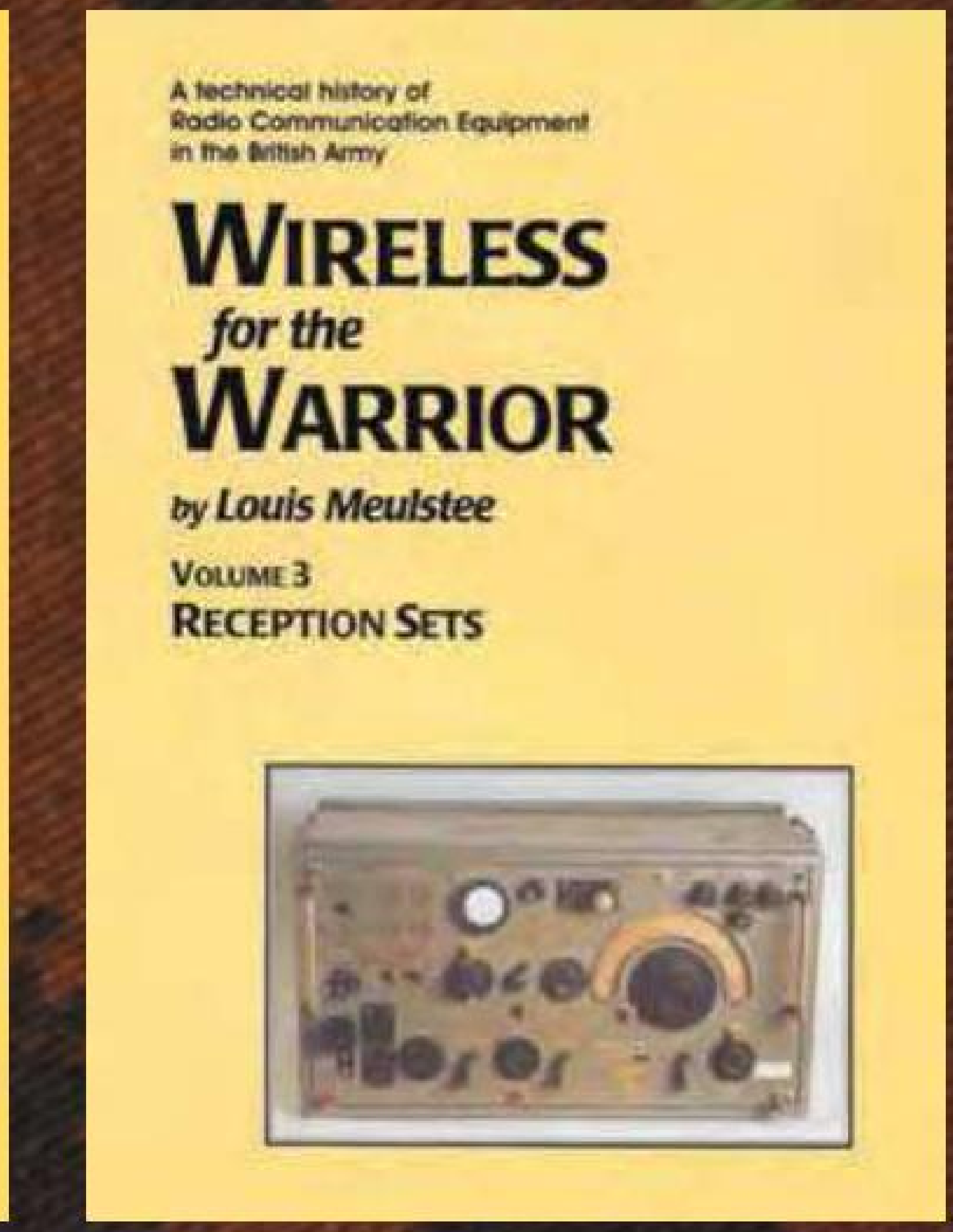

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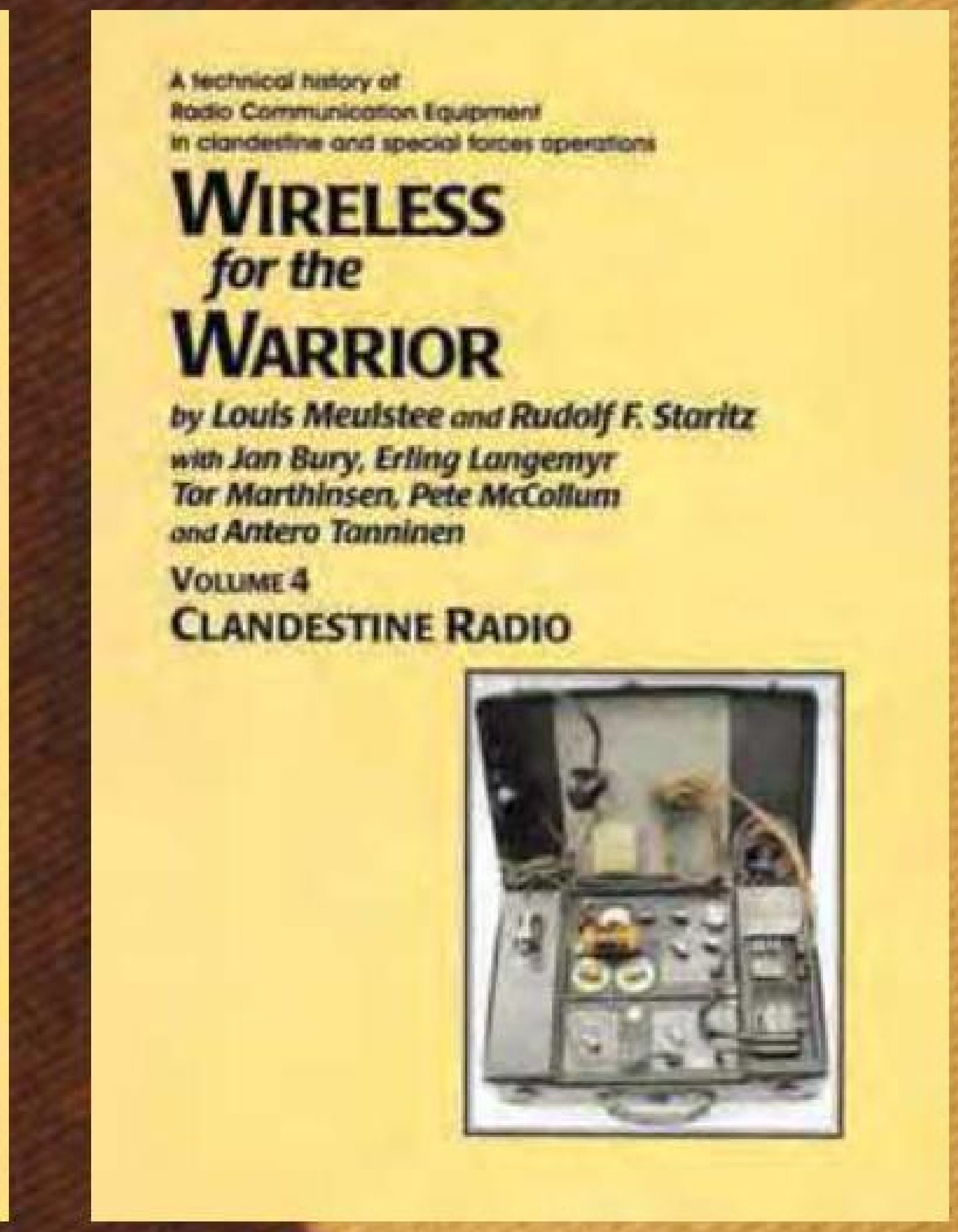

A technical history of
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in clandestine and special forces operations

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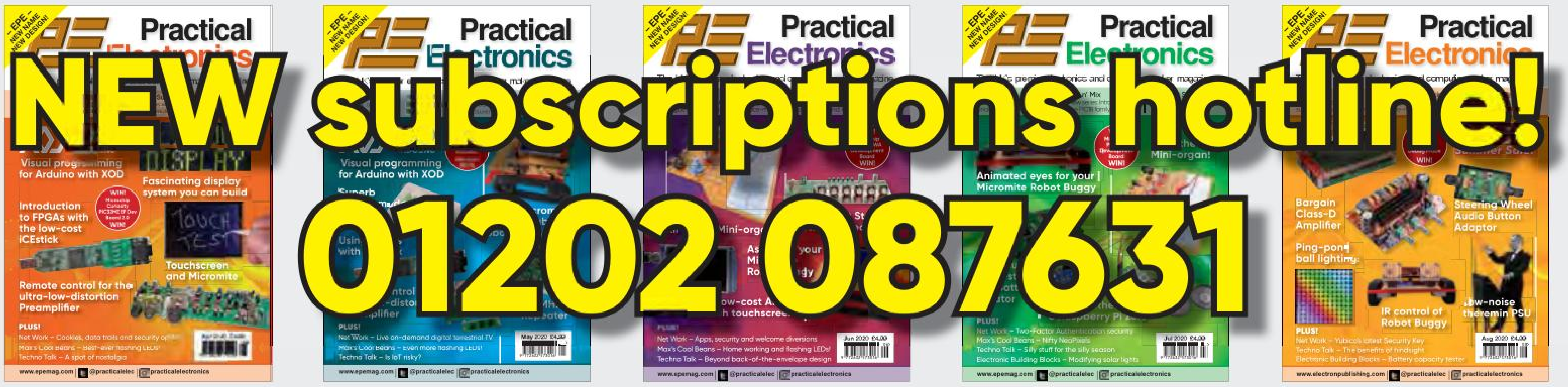

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1 Buckingham Road **Fax** 01202 843233
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East Sussex BN1 3RA **Web** www.epemag.com

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On yer bike!

Welcome to the September issue of *PE*. There are very few things to recommend a pandemic, but one positive trend has been the rise in cycling as people avoid public transport. Bicycle sales in the UK have shot up, and although currently the days are long and the nights short, a great bike light is still a must-have accessory. (Actually, it's the law after dark, and rightly so.) If you want something with a bit more optical oomph then we have just the project for you: our *Ultrabrite LED Light*.

It's not over yet, but…

I'm sure there is still a long way to go before we can declare any kind of victory over the current pandemic, but little by little some aspects of life are returning to normality.

In the UK, most retailers that sell *Practical Electronics* are now open and stocking your favourite magazine. However, if your newsagent of choice is not yet open, or you simply prefer to socially isolate for now, then don't forget you can buy *PE* online from us for exactly the same price (£4.99, postage included).

For our overseas readers, delivery is still frustratingly slow, but it is speeding up and the great news for our North American friends is that we are now resuming shipments to US and Canadian stores. So, Barnes & Noble and other retailers will soon be stocking *PE* again

Back issue downloads

It's always a slightly nerve-wracking time when a new product is launched on the shop, but I am pleased to report that our new downloads service has worked well and many of you have taken advantage of the new low prices, especially for the older issues. CDs are still available, but the downloads are immediate, cheaper and more secure. A big thank you to Alan Winstanley and Kris Thain who are the behind-the-scenes wizards making the website run smoothly.

Do remember that the downloads service is not just for back issues – we also sell the latest version for immediate download.

Summer Sale

Last, a reminder that our summer sale is in full swing. If you fancy a nice summer project, then do please see the ad on page 3 outlining the details, and then head over to the online store for some PCB bargains!

Keep well everyone

Matt Pulzer

Publisher

The **Fox** *Report*

Barry Fox's technology column

A to D: content rescue

Safe bet: everyone has a shoebox (or many) full of old analogue audio tapes and video cassettes. Buried among the drossy taped episodes of long-forgotten soaps, once-new movies that are now regularly shown free on TV and off-air audio cassette dubs of music that are now free on Spotify, there will surely be a few gems – video tapes of family and friends, bootleg audio of long-disbanded bands and off-air time-shifts of TV documentaries that now have historical value.

Anything of real interest or value needs digital dubbing, onto hard disk or memory drive, as soon as possible. Covid-19 lockdown and subsequent restrictions on traditional social activity, such as going to clubs, concerts, theatres and cinemas, has created an unexpected window of unhappy opportunity to get the job done.

Assuming the analogue media has not physically disintegrated, and you can find, borrow or buy from eBay a compatible working player, the question becomes – how to capture the best available quality with the least possible hassle, at minimum cost? Some practical tips, generated from hard-labour trial and error during my enforced lockdown, may be of use. Let's look first at video rescue.

Capturing analogue video

There are two routes to video capture – analogue and digital.

For the analogue route, plug the SCART, phono or S-Video outputs on the tape player into one of the 'Rescue your VHS tapes' capture dongles which sell for around £20-£30, and connect by USB lead to a PC. Usually the dongle comes with a disc offering simple PC software to control capture. If there is an option to burn-to-blank DVD, ignore it. DVD is a dying format, and VHS-to-DVD transfer introduces too many opportunities for something to go wrong. Burned DVDs often don't play reliably on all disc players; the discs don't last for ever and will need dubbing off again later as reliable DVD players become as rare as hens' teeth.

So, forget about DVD and the MPEG-2 compression system used for DVD. Opt instead for hard disk or stick memory with more efficient MP4 (or modern improvements on MP4).

All your video tapes will be Standard Definition and the PC software that comes with basic dongles will be SD. If presented with a resolution option, go for PAL 576/25 (or 30). By and large, anything larger is just wasting bits and storage space on coding noise.

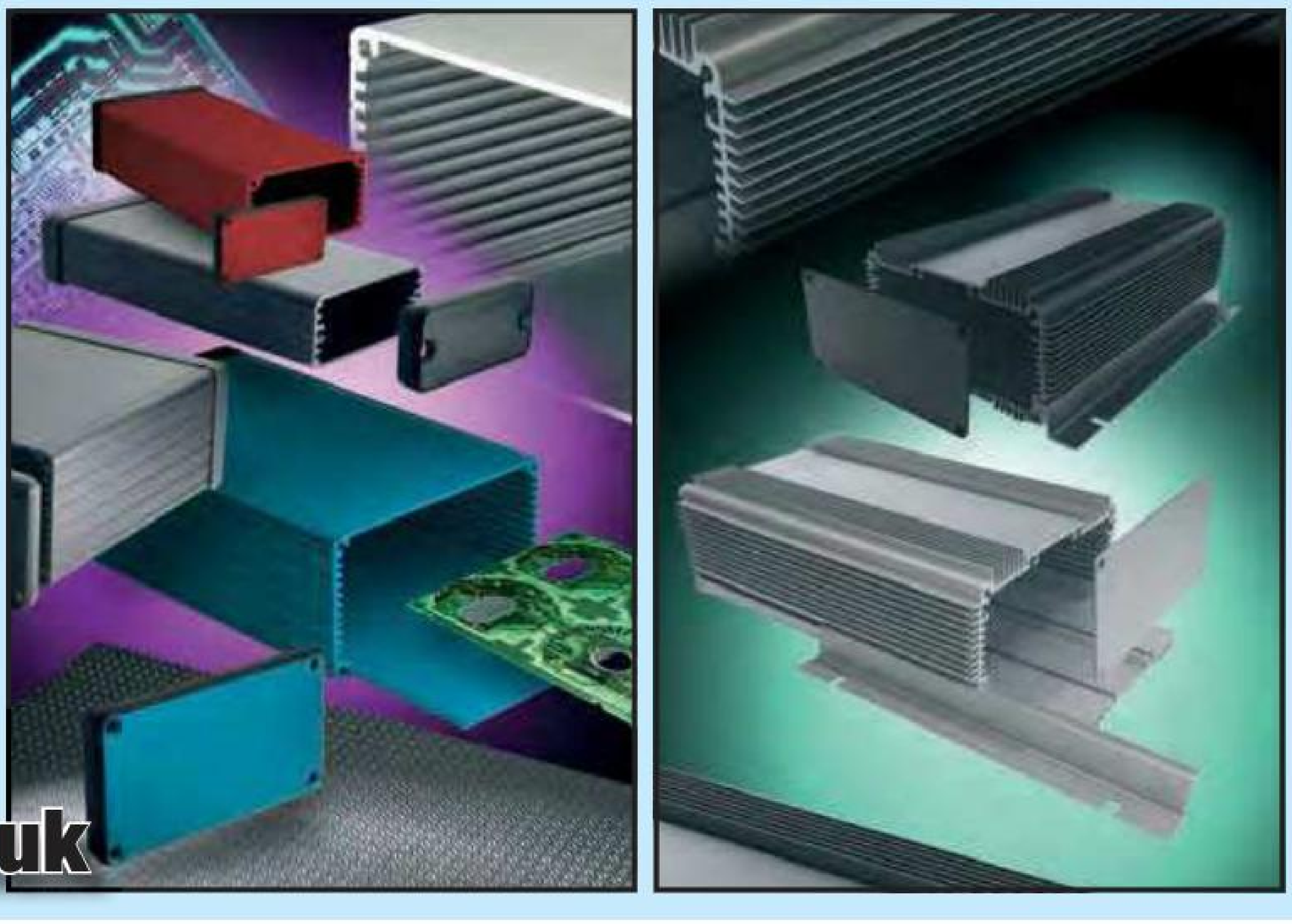
It's probably best to ignore the capture software that comes free with a dongle. It will very likely be overly simple and restrictive, and probably MPEG-2, DVD-specific. The slightly more upmarket commercial programs ArcSoft Showbiz and Hauppauge Capture are simple and easy to use, but my tip is to go for the excellent free Open Source capture program OBS (Open Broadcaster Software): **https://obsproject.com/**

Because OBS offers so many user options, it takes a bit of learning, but the effort is well worth it in the end; and a team of gallant volunteer developers keeps on upgrading OBS.

If you need to edit what you capture, my recommendation is Shotcut, another excellent Open Source program that also requires, but repays, time spent learning to use it: **https://shotcut.org/**

Games capture boxes

Instead of using a simple SD VHS-to-video capture dongle it is actually far better to use a gameplay capture device 'box', which handles HD video. These



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are sold, for instance by Hauppauge, to let computer gamers record their master moves. These device boxes take in analogue Standard or High Definition video and audio (composite or component) from a games console and use custom ICs to deliver a digital bitstream which is sent to a PC by USB. Capture software (Showbiz, OBS or similar) installed on the PC does the rest.

Games capture boxes also take in HDMI digital signals from a console, as long as they are unprotected – ie, not movies which are content copy protected by HDCP.

Games capture boxes will usually also accept SD analogue video signals from a tape deck, digitise them and send the bits to a PC with installed capture software. It's all just bitstreams to the boxes.

(For the sake of completeness, it is possible to buy separate boxes which convert protected HDMI digits to unprotected analogue component video; but that's a whole other story).

My tip, though, is to go the second and 'more digital' route, and get the off-tape analogue video and audio signals into the digital domain as quickly as possible. This is easily done with a simple SCART-to-HDMI converter, costing less than a tenner online (often direct from China). Use a phono-to-SCART plug or cable from the tape deck to the £10 converter, and a bog-standard HDMI lead from the converter to the gameplay capture device.

The signal from the analogue tape is inherently unprotected, so the HDMI conversion is also unprotected, and the capture box treats it like a gameplay signal – and sends an unprotected bitstream down the USB cable to the PC and any installed capture control software such as OBS.

This works well – I've been doing it during lockdown.

Pricey boxes…

The one fly in the ointment is the cost of gameplay capture box. The better ones cost well over £100. Beware cheaper ones (around £50 plus) which will not successfully connect by USB to a PC; instead they record direct to a USB memory. Often there will be limitations on how large the memory can be (max 32GB) and how it must be formatted. It's not easy to monitor what is being recorded; and very likely the recording will be broken down into 2GB chunks. It then needs stitching together. Although this can be done with software, such as the excellent Avidemux, available free from several sources, it's more work to be done. Storing a full file, direct to an HDD, is much more convenient: **https://sourceforge.net/projects/avidemux/**

…but watch this space!

Salvation on capture box cost may however be at hand, in the shape of low-cost HDMI-to-USB converter dongle sticks from China. I hear great things about them and have one on order for under a tenner. Watch this space for news of what hopefully arrives before Christmas by sea mail.

In the meantime, be aware. As with the SCART-to-HDMI converters, it looks as if many vendors are packaging the same chipset in slightly different casings, at widely varying prices. You may not get more by paying more.

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Marconi 2955B Radio
Communications Test Set – £800

The perils of an enquiring mind...

Techno Talk

Mark Nelson

...and of streaming channels that stop working and smart TVs that lose functionality when they fail to update as expected. But it's not all bad news and this month we have some good tidings regarding lowish-cost gadgets for hands-on electronics constructors. There's plenty to take in, so let's crack on.

Many of our character traits are inherited, and ever since birth I have suffered from an over-enquiring mind (from my mother, for what it's worth). I am told that as a toddler I used to scare the living daylights out of my parents by playing with the aluminium studs that were used to fasten the cuffs of a newly bought shirt. My father would never discard anything that might come in handy (another attribute that I inherited), so they were left lying around. No, I did not try eating the studs, but I did make the technical discovery that these studs were a perfect fit for the round openings in 5A socket outlets that were common in houses in those days. It's a miracle that I did not electrocute myself!

Electrical matters fascinated me at that tender age – and they still do. I always wanted to know how things worked and why our family said '*eye*-ther' but other people pronounced the word '*ee*-ther' (please don't tell me it doesn't matter!). For me, everything had to be consistent and logical (I know what you're thinking) and easy to understand. Many people are happy to buy their DIY needs at B&Q, but that's not enough for me. I was unable to rest easily until I discovered that the firm's founders were called Richard Block and David Quayle. Enough of the prelude, let's move on now to some practical electronics.

ROKA — or is it really RoKa?

Almost every reader of this magazine uses ROKA connectors, but possibly without using that name. More likely you call it a DC connector, barrel connector or tip connector (the last because many low-voltage DC power supplies are provided with a dozen or so 'tips' that fit the output cable). Although these low-voltage power connectors are a German design, they are now used all over the world. In the rest of Europe, they are widely called ROKA or RoKa connectors, a name that comes from the initials of the Robert Karst electronics company in Berlin, which was responsible for either inventing or popularising them.

And popular they are, with at least two dozen different sizes. As Wikipedia laments, many appear quite similar to each other, yet are not quite mechanically or electrically compatible. In addition to a plethora of generic designs of these connectors, there are at least two different national standards — EIAJ in Japan and DIN in Germany, as well as the JSBP connector used on some laptop computers. That's only to be expected, however, if you recall the old saying that runs, 'We favour standardisation fervently; that's precisely why we support so many of them'!

Needless to say, there's not even any agreement on whether the centre pole of these connectors should be positive or negative, although older devices tend to favour a negative centre pin and newer ones are centre-positive. Another rule of thumb is that consumer goods have a positive centre pin, while professional gadgets, test instruments and accessories for electric guitars opt for centre-negative.

Let's get practical

OK, what do you do when you are given a Sony Walkman to test and it has a barrel connector slenderer than you have ever seen? Other than forking out £30 for a no-name power supply that claims to be fully compatible (even though the photo suggests otherwise), are you stumped? Not now, because you can just head off to Amazon and search for 'Aceyoon DC Barrel Jack Adapter' (**https://amzn.to/2AhIJhY**). This is a 38-piece set of DC power tips in virtually every pattern known to mankind. Each power connector tip can plug into a standard 5.5 × 2.1mm male connector and adapts a power supply to all of the other 38 sizes. The advertising indicates that it is intended primarily for 'road warriors' (do people still use this 1980s expression?) but of course it is equally useful in the home or workshop. Priced at £12.98, it's hardly expensive and the quality is impressive.

Another handy and affordable gadget I bought recently was a tool for forming wire links and bending component leads (eBay UK item 232645791410). Yes, you can do this work without a jig but if you are populating a large PCB, it helps to use one of these plastic tools to ensure every R and C fits the holes drilled in the board. The price is £6.95 with free postage, and I am sure that the same tool can be found elsewhere on eBay and other websites.

It reminds me of a similar plastic tool that came free with this magazine as a cover gift back in the 1970s or 1980s. I think I still have mine somewhere, but it was designed for those chunky big components that we used half a century ago!

IoT = Internet of Trouble?

No, it's not just my opinion, nor do I use any IoT gizmos. But it's clear that there's trouble afoot for many people who have either welcomed the Internet of Things into their homes or else are planning to join the smart-home set in the future. That's the clarion warning coming from Scott Helme, a security researcher, entrepreneur and international speaker specialising in hacking and encryption. The problem concerns a specific kind of security certificate (the 'root certificate') that authenticates websites that you or your network connect to. These can expire, leaving you none the wiser, with negative consequences. Some users have found streaming channels no longer working and payment processors having problems too. If you use smart appliances, I encourage you to read his webpage at: **https://bit.ly/pa-sep20-rca** – but if that leaves you as baffled as I am, you can read much more accessible assessments on other webpages at: **https://bit.ly/pe-sep20-ssl** and **https://bit.ly/pe-sep20-reg**

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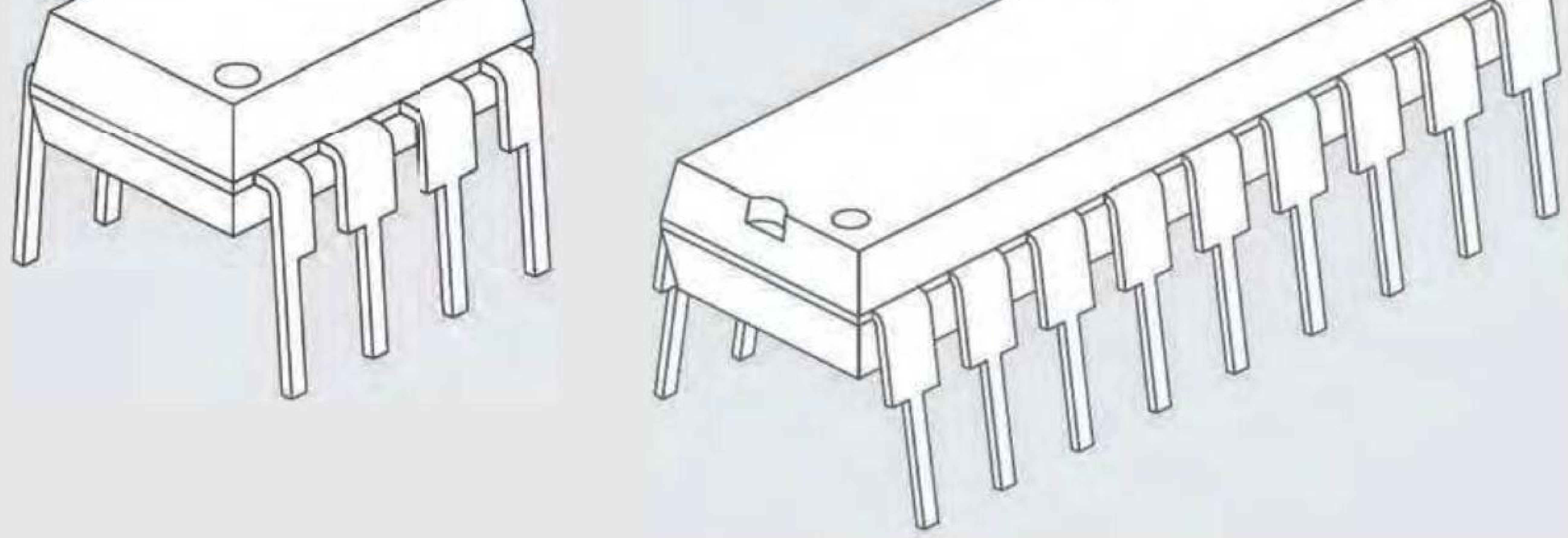

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Net Work

Alan Winstanley

Lights, camera, action! This month, *Net Work* returns to the complex world of IP security cameras.

Back in Net Work from the December 2015 issue, I explored the emerging market of IP security cameras that were designed for home network users. After suffering mixed results with several cheap unbranded ones, I chose a UCam 1080p bullet camera. It was a sturdy mid-priced product that offered IP67 protection, infrared, one-way audio, Wi-Fi and Ethernet, along with an SD memory slot. Snapshots and short video clips could be saved to a NAS drive (there was no cloud storage at that time) and the UCam app allowed video to be viewed remotely on a mobile phone, via a wireless hotspot.

Camera set-up

Using the UCam became quite a learning curve, so this month's *Net Work* outlines a few IP camera practicalities that I stumbled on over the years.

This type of camera needs initialising using an Ethernet cable. Once the Wi-Fi SSID and IP address are configured in the camera, then in theory Ethernet is no longer needed and the camera should operate wirelessly. Despite this, it isn't necessarily a great idea to mount it high up in an inaccessible location (see later). Also, when locating a camera, consider how the sun travels through the day and site the camera to avoid direct sunshine; at night, a camera's IR illuminator will cause dazzle if it's, for example, indoors on a window ledge, because the IR light reflects back off the glass and washes out the video. It's sometimes better to disable IR and rely on ambient street lighting or consider a separate (possibly external) IR illuminator lamp (eBay).

I found that many cameras of this type sprout a clunky power and Ethernet block, with maybe a paltry 12-inch long lead. The connector block might need a 1-inch hole or so to pass through a house wall, possibly needing an SDS drill followed by some sealant or cement. Otherwise, pencil in a weatherproof junction box to house the camera connectors, before routing the wiring indoors. I also plugged the camera's Ethernet port with an RJ45 rubber dust cap (eBay) once setting up was completed.

And of course, the camera requires a DC supply, for which DC extension leads are commonly bought: mains outlets are seldom located where they're needed!

Network camera practicalities

Looking at some software setup snags, this camera's settings are accessed by logging in with a desktop web browser, which highlighted the next problem: 'Live View' stopped working because popular web browsers stopped supporting the legacy Flash-based viewer, so separate desktop software (supplied) is used instead. This camera's settings menu also configures motion detection zones, but I found that birds or trees blowing in the wind triggered false alarms. The software might offer scheduling and alerts by email or uploading snapshots to a web server, along with the usual arcane network and storage settings. It proved best to give both the camera and the NAS their own static IP addresses. That way, if the router was powered down or reset, the IP camera and NAS would still handshake properly once the network was restored.

My camera has built-in optional storage, although you can still record images to a NAS. One problem is the risk of data loss if the camera is stolen! Many modern camera systems now promise cloud-based storage, but free services might only have a short file retention period. Typically, subscription-based cloud storage is offered (assuming you're satisfied with third-party security) but watch for charges levied for additional cameras.

One risk is that makers will not future-proof apps or software, and products may become crippled at short notice. On 30 June, Belkin pulled the plug on its WeMo NetCam range as its cloud-based video platform was shutting down, leaving 'many users of the WeMo NetCam with a product they can no longer use,' as Belkin helpfully recognised. Also, last November, the US chain Best Buy dropped support for their own-brand Insignia smart device range, leaving owners of their 'smart' appliances (including smart cameras) stranded. This kind of product uncertainty does not endear users to the smart-device sector.

Apart from using Wi-Fi to hook up an IP camera, an Ethernet lead can be used on some (but not all) home cameras. Where Wi-Fi coverage is dodgy, if a mains outlet is available then Homeplug powerline communications (PLC) adaptors such as the Devolo range can conveniently create Wi-Fi access points and/or provide an Ethernet port, by using the ring mains to carry Internet traffic. Devolo has been covered extensively in *Net Work* in the past and there are plenty of used Devolo devices on eBay. A cheap way of implementing PLC networking at home would be to try some second-hand Devolo DLAN 500 units – remember you need to connect one mains 'transmitter' directly to your router, and plug in separate Wi-Fi Add-On Adaptors around the home or outbuildings (up to 300m away). Note the new generation Devolo 'Magic' mesh range (offering up to 2.4 Mbps) is not compatible with these earlier DLAN devices.

In fact, the author installed some extra DLAN 500 repeaters recently for some trials, but after a while it was found that the IP camera had stopped responding for some reason. Checks showed that the NAS had also stopped recording a few weeks earlier! Eventually, it looked like a total camera reset might be needed: that's one good reason not to site such an IP camera too far out of reach – setting it up again would mean hooking it to an Ethernet lead and initialising it all over again. Then the penny dropped: after adding those Devolo DLAN Wi-Fi units, I'd also renamed the Wi-Fi SSIDs,

HeimVision's range is typical of current battery-operated home security cameras.

thereby accidentally cutting off the IP camera's Wi-Fi access in the process! I reset the camera after rigging up a temporary Devolo Ethernet port a few yards away, and the camera burst into life on Wi-Fi once again.

Network camera innovations

Today, there is more choice than ever and some of the latest user-friendly smart cameras address some of these drawbacks to make installation and operation far simpler. Amazon's Blink XT2 starts at £99 and is typical of the latest wave: it's a compact weatherproof 1080p Wi-Fi camera with two-way audio. Lithium batteries promise up to two-years life (but very much less – reportedly as little as a month – if you use video and audio monitoring extensively, and swapping batteries is fiddly). For indoor use, a micro USB power port allows mains operation (adapter not included). Blink is intended for smaller areas and is Wi-Fi only. It uses a proprietary mains-powered 'sync module' (hub) to broadcast video. Some users complain about time lag, but what it lacks in performance it makes up for in ease of setting up. It's possible to go further and view on an Echo Show LCD or link multiple cameras with the Alexa app as well as using voice control. Furthermore, an Amazon Fire Stick would enable viewing on a TV (as seen on **https://youtu.be/gty7XfUsBf0**). Free limited online storage is included.

Google's Nest Wi-Fi cameras require DC power and are surface-mounted using simple magnetic 'universal joint' hardware (see **https://youtu.be/wG3F8xzhPlo**) so they are not exactly pilfer-proof. It has a speaker and microphone, and three hours of cloud storage is provided free; or choose 'Nest Aware', which costs from £5 a month covering all your Nest cameras. A single Nest Outdoor camera is £179.

Cameras get a solar boost

A plethora of similar-looking IP cameras is now available, often badged with unrecognised brands so, before investing, it's really useful to see what other users say in product reviews. No consumer IP camera is perfect and whether a product performs well in practice and is well supported can be down to potluck. Several branded security cameras stood out, including Reolink's Argus Pro outdoor camera with audio, SD storage, and a self-contained battery topped up by a solar panel. HeimVision's HMD2 also seems well regarded and a solar recharger is available separately. The eufyCam 2C 1080p IP67 wireless camera promises 180-day battery life, anti-theft alarms and Amazon Alexa compatibility. Video is encrypted and stored internally on a memory card and technical support seemed to be highly rated.

Simplisafe promises whole-home monitored protection, including a security guard call-out if needed.

The US home security firm SimpliSafe has now entered the UK and offers whole-home protection with wireless sensors, glass-break alarms, smoke detectors, flood alarms, panic buttons and smart cameras. Uniquely in this market, SimpliSafe also has a professional monitoring option that can, following confirmation of an incident via cameras, send the police and a security guard to your residential property at a low cost. More details are spelt out on their website at: **https://simplisafe.co.uk**

Doorbell wireless video cameras are also catching on, especially because some 40% of US households have been victims of doorstep package theft or 'porch piracy', according to **Security.org** (YouTube is full of 'porch pirate' entrapment videos featuring booby-trapped parcels). Wireless doorbell cameras include the Google Nest Hello and Amazon's Ring, but there are many others.

Huawei we go again

After more political wrangling, Britain seems to be on the verge of cutting Huawei adrift. The UK had thus far chosen to 'mitigate' Huawei's involvement in the country's telecoms network through the Huawei Cyber Security Evaluation Centre (HCSEC) Oversight Board. This task force revealed some sloppy coding and security practices and broken assurances that the UK's National Cyber Security Centre (NCSC) still felt were manageable, nonetheless. Further US sanctions on American chip design software and fabricators means that, ongoing, alternative chips might have to be sourced, making it harder to warrant the security of the 5G telecoms network. At the time of writing, the NCSC was revisiting Britain's relation with Huawei. Meantime, Huawei's plans to build a £400 million opto-electronics research site in Cambridgeshire has received initial approval by the local authority, despite American opposition: Britain's local planning authorities never get involved with politics.

SpaceX continues to lob Starlink satellites into LEO (low-earth orbit), with ten launches totalling nearly 600 satellites so far. The US FCC had questioned whether the network's latency would in fact be low enough (100ms or less, according to them) for it to qualify for the US Government's $20 billion 'Rural Digital Opportunity' programme intended to bring Internet access to rural districts. The FCC has since softened its approach to allow SpaceX to bid for traffic.

Boldly going...

SpaceX also launched a second GPS III satellite into orbit for the 'US Space Force', making three satellites in total. These latest-generation GPS satellites have higher accuracy and anti-jamming technology – see: **www.spaceforce.mil**

Britain has been sidelined by the EU in its Galileo satnav programme, despite being an investor in the past. Earlier this year, in pre-Covid-19 times, the UK trumpeted a hard-to-believe £5bn programme to build its own satnav network, but these ambitions have since been downsized. Instead, the UK has bought a £400 million stake in the bankrupt OneWeb satellite network which may be a fast-track alternative to building a GPS system from scratch – if the technology allows. India's Bharti Global has matched the bid for this LEO Internet service, though reports mentioned nothing about offering GPS.

Anycubic's UV Photon Zero is a low-cost introduction to 3D UV resin printing.

China has polished off its own GPS system with the 35th launch of a Beidou Navigation Satellite at the end of June, in a programme intended to make China self-sufficient (the EU said the same about its own dependence on US GPS, which prompted the EU Galileo programme).

In other news

Amazon has launched the Echo Auto, an in-car adaptor allowing drivers to access Alexa services while on the road. Powered by a cigar lighter socket or USB port, Echo Auto connects to the car audio via Bluetooth or a 3.5mm lead, and uses the Alexa app on your mobile phone. It has eight microphones and has been optimised to work well over road noise, Amazon says. It's available for £49.99 from Amazon and major retailers.

After killing off its five-year old Dash stick-on hardware buttons that enabled seamless re-ordering of goods, Amazon has ditched their barcode-scanning Dash Wand, a quirky product-ordering gadget that never really caught on. Virtual Dash buttons live on in the Amazon app.

The world's most powerful offshore wind turbine, the 12MW GE Haliade-X (see *Net Work*, January 2020) has been granted a type approval certificate by the global certification body DNV-GL based in Norway. It's a milestone that allows GE to bring the wind turbine from prototype to serial production, says GE.

UV-curing resin printers seem to be catching on, with small 3D printers available for as little as £200. The Anycubic Photon Zero UV Photocuring 3D Printer, for example, is available from Amazon and prints objects up to 95 × 54 × 150mm. Single-colour UV resin typically costs £41 per litre.

Readers are reminded to be vigilant when receiving SMS PIN numbers for 2FA authentication (described in previous months). It was recently reported that one scammer, described as 'being from a bank's fraud prevention unit and very convincing', knew his victim's account and cellphone number and called to glean from him a 2FA PIN number, after the bank alerted the victim of an attempted hack. Revealing the PIN that way would have enabled the crook to finish off the fraudulent transaction.

PayPal has introduced Honey, a discount voucher 'bot that automatically applies the best promo codes on Internet checkouts. You can install the Honey extension for your browser and it has already saved the author a few valuable pounds shopping on a well-known coffee pod website. Sign up free at: **www.joinhoney.com**

That's all this month – see you in the next issue for more *Net Work!*

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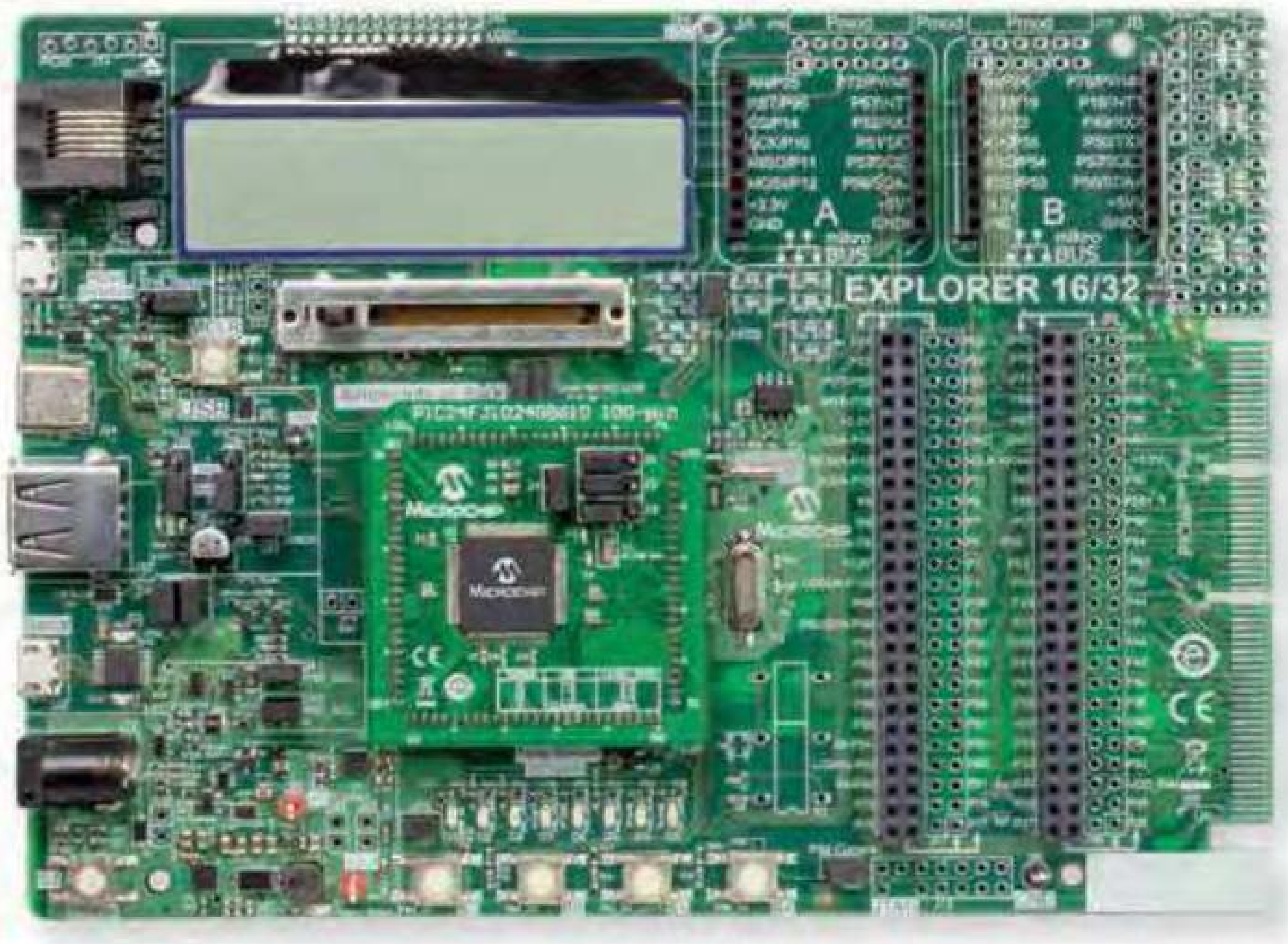
In addition to the hardware features provided by the board, hardware expansion is possible through the use of PICtail Plus daughter cards and mikroBUS accessory boards. Coupled with the integrated PICkit-On-Board (PKOB), MPLAB ICD 3 In-Circuit Debugger or MPLAB REAL ICE real-time emulation and debug facilities, it enables faster evaluation and prototyping of applications.

Included with the Explorer 16/32 Development Kit are:

- Explorer 16/32 development board
- 16-bit high memory, super-set device – PIC24FJ1024GB610 Plug-In-Module (PIM) (MA240023)
- Two USB cables (USB A to Type-C and micro-B cables).

Free-to-enter competition



Microchip
Explorer 16/32 Development Kit

How to enter

For your chance to win a Microchip Explorer 16/32 Development Kit or receive a 20% off voucher, including free shipping, enter your details in the online entry form at:

https://page.microchip.com/PE-Explorer-Kit.html

Closing date

The closing date for this offer is 31 August 2020.

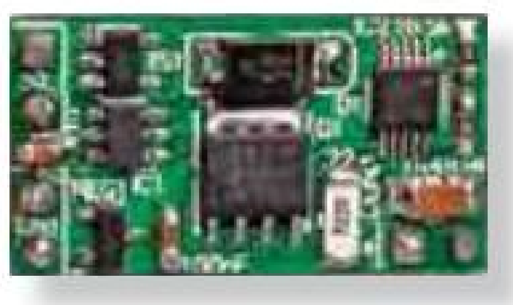
May 2020 winner

Kemuel Nesbitt

He won a Microchip MPLAB ICD 4 In-Circuit Debugger

MPLAB ICD4
Microchip

ULTRABRITE LED PUSHBIKE LIGHT



This tiny (22 × 12mm) circuit board is a high-efficiency LED driver that delivers a constant 1A or 2.2A. You can use it with a 12V white LED array to make a (very!) bright bicycle light, a torch or another light source. It can be powered from a lithium-ion or LiPo battery pack but there are other options. It also has brightness control and a flashing function. It's a very compact and modern design, for advanced constructors.

Design by Daniel Doyle – words by Nicholas Vinen

There are plenty of bicycle lights and LED torches on the market, but there are certain advantages to building your own. You get to choose the battery, so you could use a high-capacity rechargeable lithium-ion or LiPo battery that would last for many hours of use. These are not terribly expensive, and can last for many years if treated well.

You also get to choose the LED(s), so you can use a really efficient one for maximum battery life and brightness.

And you can also tailor the optics to suit your needs. You can build it with a tight, bright beam or a wider beam to improve your visibility to objects not directly in front of you.

You don't necessarily have to use this driver board for a bike light or torch. It could be used for caravan lighting, to light the bed of a utility vehicle or the cargo area of a van, in a shed, or wherever you need a bright light but don't have ready access to mains power. The driver board is tiny, so it can be tucked away just about anywhere. Add an LED and a battery, and away you go.

It has a flashing mode and two reduced brightness options that you can use for longer battery life. You can also build a higher-power version of the circuit to suit more powerful LEDs.

It's a generally useful device. It's also a good way to learn about switchmode power supplies and LED driving.

And while it's designed to drive LEDs, it isn't necessarily limited to only doing that. With a few small changes, this board can be used as a constant current source for a variety of applications.

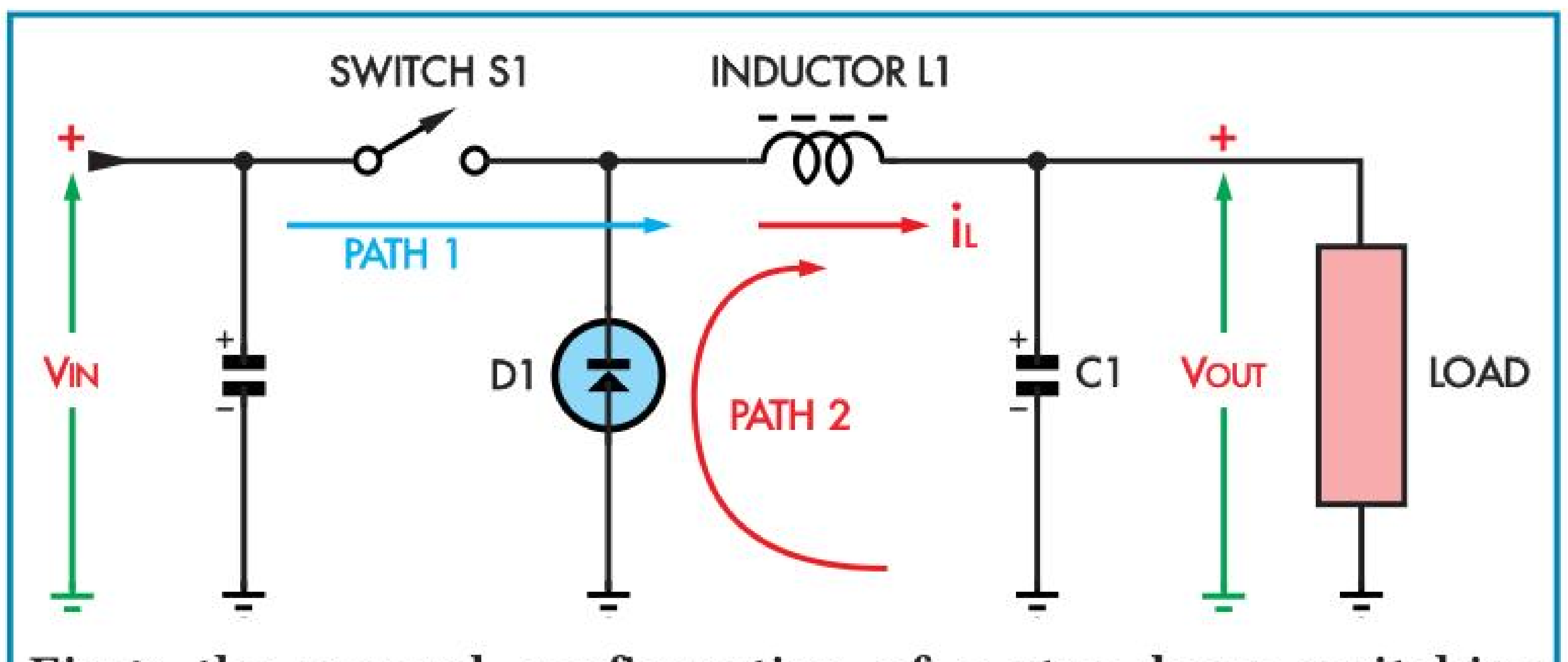


Fig.1: the general configuration of a step-down switching DC/DC converter, also known as a 'buck' converter. When S1 is on, current flows through it and inductor L1 to the load, charging up both capacitor C1 and L1's magnetic field. When S1 switches off, the magnetic field starts to collapse, which forces current to continue to flow. This must come from ground, via D1, which along with the charge in C1, causes the load voltage to drop slowly until S1 switches on again.

Operating principle

This LED driver is a 'buck' step-down DC/DC converter with current regulation. It efficiently reduces the 15-21V battery supply voltage down to around 12V, as required by the LED array. The LED voltage is not regulated directly; rather, the circuit attempts to maintain 1A through the LED array, at whatever voltage is required, from virtually nothing up to the full input voltage.

Fig.1 shows the basic configuration of a buck regulator. Switch S1 is electronically toggled on and off rapidly to control the current through inductor L1. When S1 is on, the current flowing through L1 increases at a rate determined by its inductance and the voltage across it.

Some of this current may flow through the load while the rest charges up capacitor C1. L1's magnetic field also charges up as the current flows.

When S1 switches off, the magnetic field starts to collapse and this forces current to continue to flow into the load and C1, although at a reducing rate.

Since current can no longer flow through S1, it must instead come from the circuit ground and through diode D1, effectively flowing in a loop through D1, L1 and C1/the load, and then back to ground.

It is the energy stored in the magnetic field which makes this an efficient circuit, as the voltage drop across L1 is not dissipated as heat; most of that energy is stored while S1 is switched on, and recovered when it switches off.

By controlling the duty cycle of S1, we can control the current through L1 and thus the average voltage across C1.

Circuit description

Fig.2 shows the LED driver circuit, including the internal details of the LM3409MY controller. In this case, the switch shown in Fig.1 is actually a MOSFET (Q1).

You should be able to see all the other components from Fig.1 in this circuit, with the addition of a 0.22Ω current-sense resistor between the supply bypass capacitors and the source of Q1.

Q1 is a P-channel MOSFET, which means that the controller IC can switch it on hard by pulling its gate down to 0V without needing a boosted gate-supply rail. That means if the battery is almost fully discharged, the highest possible LED brightness can still be maintained, as there will be a minimal voltage drop in the circuit (around 0.25V, mostly due to the current-sense resistor).

IC1 is powered from pin 10 (V_{IN}) and it has an internal regulator (V_{CC}REG.) producing a voltage at pin 9, labelled V_{CC}. This is a 'negative' regulator which produces a voltage rail that is relative to V_{IN}, but about 6V lower. The external 1µF capacitor filters this rail.

Internally, V_{CC} is fed to the MOSFET gate driver, and this provides the voltage that the MOSFET gate is pulled down to (via pin 6) to switch it on. This gives the MOSFET a gate-source voltage of –6V, more than enough for Q1 to be fully in conduction. To switch it off, pin 6 is pulled up to V_{IN}, so the gate-source voltage is reduced to 0V.

The benefit of this scheme is that it allows V_{IN} to be higher than it otherwise could be. A typical MOSFET has a maximum gate-source voltage rating of ±20V. If the MOSFET gate were pulled to 0V to switch it on, that would mean that V_{IN} could not exceed 20V. Our recommended 5-cell Lithium-ion battery has a fully charged voltage of 21V, and the circuit can operate to at least 30V thanks to this internal regulator.

When S1 is on, the current flowing through it and inductor L1 is sensed via the voltage developed across the 0.22Ω resistor. Both ends of this resistor are connected to a differential amplifier within IC1. The regulated current is determined by the value of the current-sense resistor, and the value connected from the I_{ADJ} pin (pin 2) to ground, if any.

In this application, no such resistor is fitted. If a resistor is fitted there, it changes the 1.24V reference voltage which controls the voltage divider formed by the internal resistors labelled 'R' (at pin 8) and '5R'.

This photo of a 'naked' bike light really doesn't do the LED justice! It is so bright that you risk temporary vision impairment from looking into it – trust us, that is from experience, so DO NOT do it! You can also see just how small the controller board is from this pic. The LM3904 on this board may get quite warm at higher currents, especially if it's in close proximity to the LED and/or if in a small housing. In this case, a small heatsink is suggested. The battery is a 5-cell, 18.5V, 5000mAh high discharge Li-Po by Turnigy.

Features and specifications

- *Can power a 12V LED array from a 5S (18.5V) lithium-ion/LiPo battery*
- *Operates from 5-25V (minimum LED operating voltage + 2V)*
- *Delivers 1A (12W for 12V LED) or 2.2A (26W for 12V LED)*
- *Can be used with a wide variety of high-brightness LEDs, including 6V and 12V (nominal) types*
- *Three brightness settings plus flashing mode with pushbutton on/off and mode control*
- *Low quiescent current when off (around 1mA)*
- *Under-voltage lockout*
- *Overheating protection*
- *High efficiency; typically more than 90%.*

With no external resistor, 1.24V appears across the '5R' resistor, meaning that 0.248V (1.24V ÷ 5) appears across the upper 'R' resistor. Therefore, a similar voltage must be developed across the external sense resistor for the current amplifier's output to change polarity. This sets the peak current to 1.13A (0.248V ÷ 0.22Ω), resulting in an average LED current close to 1A.

IC1 uses a 'controlled off-time' scheme for regulation. With standard PWM, the pulses applied to the gate of Q1 would be at a fixed frequency but with a varying duty cycle. With the controlled off-time scheme, Q1 is switched off for the same time after each pulse; the on-time varies to control the duty cycle. This results in a variable switching frequency.

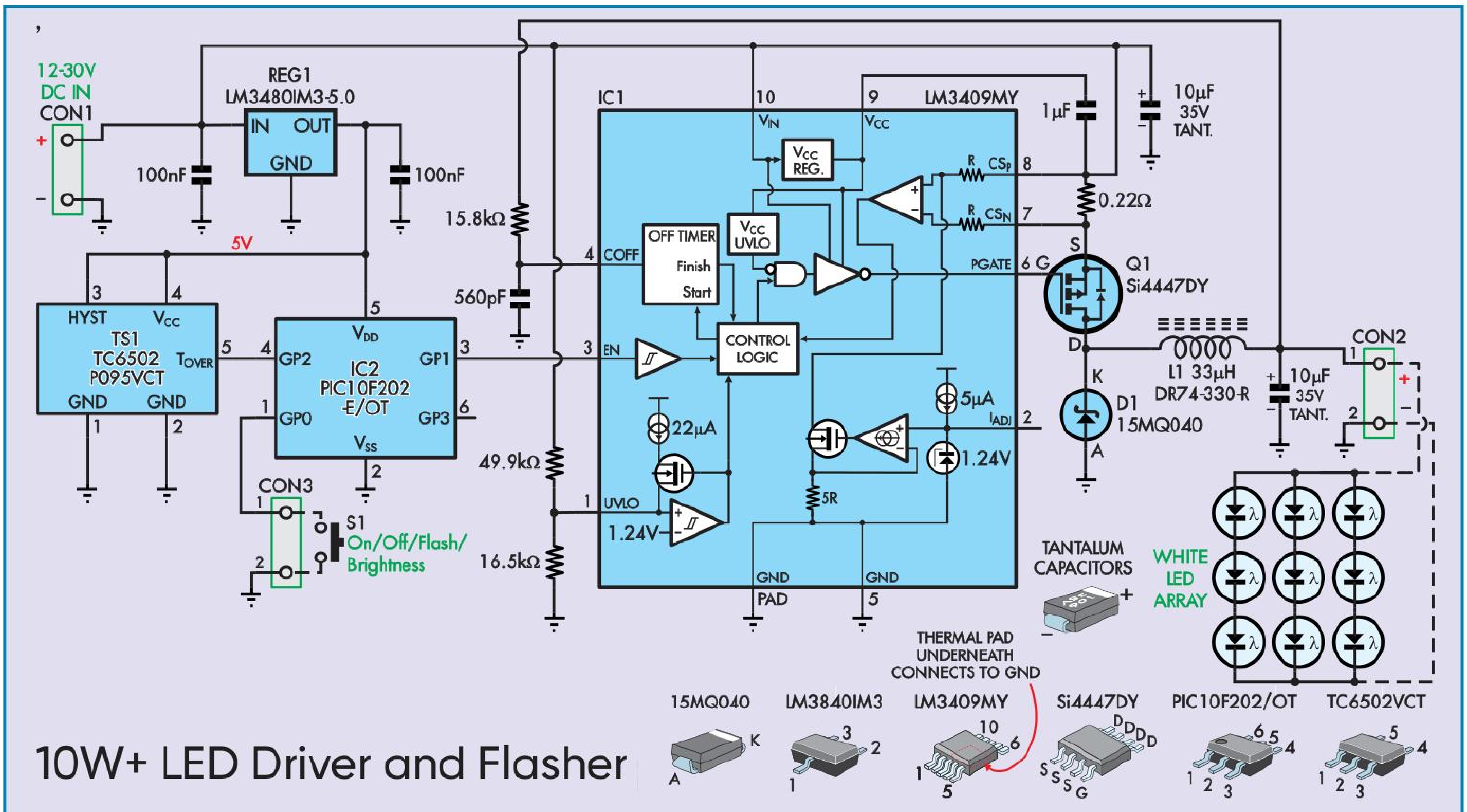
The advantage of this scheme is that it's easier to stabilise the feedback loop to prevent sub-harmonic oscillation. This avoids the need for external loop-compensation components. The combination of the 15.8kΩ resistor from the output to pin 4, and the 560pF capacitor from pin 4 to ground, sets the fixed off-time to be very close to 1µs. So with a 50% duty cycle, the switching frequency will be around 500kHz.

Diode D1 is a 1.5A schottky diode with an especially low forward voltage of 0.43V at 1.5A, for maximal efficiency.

The resistive divider at pin 1 (UVLO) sets the input supply under-voltage lockout threshold to 5V (=1.24V × [1 + (49.9kΩ ÷ 16.5kΩ)]). The internal switched 22µA current source adds 363mV (16.5kΩ × 22µA) of hysteresis, so that the switch-off threshold is 5.363V.

This was chosen to shut down the circuit before the external control circuitry no longer has enough voltage to run, and to allow lower-voltage batteries and LEDs to be used. It is expected that your battery will have built-in over-discharge protection and so will cease supplying current before it is damaged.

If not, you would have to change these divider values to protect your battery. For example, a 5S Li-ion or LiPo battery should not normally be discharged below 3V per cell or 15V total. So you could change the 49.9kΩ resistor to 183kΩ (16.5kΩ × [(15V ÷ 1.24V) – 1]) (180kΩ would do) and the LED drive will automatically shut off when your battery drops below 15V.


10W+ LED Driver and Flasher

12-30V DC IN
CON1
REG1 LM3480IM3-5.0
IN OUT GND
100nF
100nF
5V
15.8kΩ
560pF
49.9kΩ
16.5kΩ
TS1 TC6502 P095VCT
HYST VCC TOVER GND GND
IC2 PIC10F202 -E/OT
VDD GP2 GP1 GP0 GP3 VSS
CON3
S1 On/Off/Flash/ Brightness
IC1 LM3409MY
VIN VCC
VCC REG.
OFF TIMER Finish Start
VCC UVLO
CONTROL LOGIC
COFF EN UVLO
22µA
1.24V
5µA
IADJ
1.24V
5R
CSP CSN PGATE
GND PAD GND
1µF
10µF 35V TANT.
0.22Ω
Q1 Si4447DY
L1 33µH DR74-330-R
D1 15MQ040
10µF 35V TANT.
CON2
WHITE LED ARRAY
TANTALUM CAPACITORS
THERMAL PAD UNDERNEATH CONNECTS TO GND
15MQ040
LM3840IM3
LM3409MY
Si4447DY
PIC10F202/OT
TC6502VCT

Fig.2: this circuit diagram also shows the internals of the LM3409 IC. It's a constant off-time switchmode current regulator driving a P-channel MOSFET. The internal negative regulator (V_{cc} REG.) takes the supply between pins 10 (V_{IN}) and 5 (GND) and produces a third rail at pin 9 (V_{cc}) which is around 6V below V_{IN}. This determines the low (on) voltage for the MOSFET gate, allowing a supply voltage higher than its gate-source rating. Note the 1µF filter capacitor between V_{IN} and V_{cc}. The LM3409 IC does get quite warm during operation – heatsinking may be required, especially in a small housing.

Control circuitry

Pin 3 (EN, enable) of IC1 is driven from the GP1 digital output (pin 3) of 6-pin microcontroller IC2. This pin is driven high to light the LED or low to shut it off. It can be modulated (eg, using PWM) to provide dimming.

Microcontroller IC2 provides seven different modes: light off, low, medium or high brightness (continuous) or low, medium or high brightness (flashing).

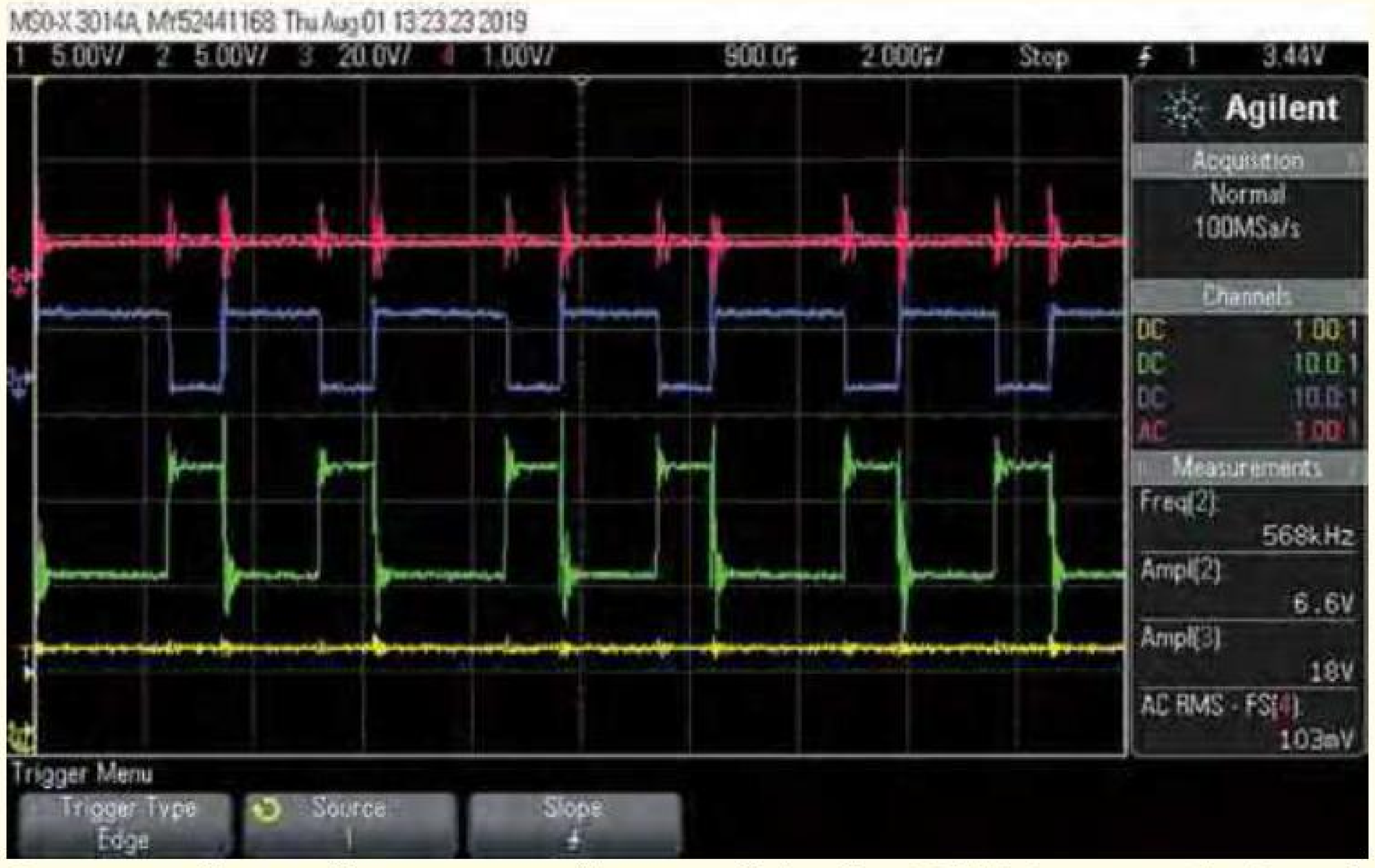
These are all achieved by pulse-width modulating or switching the GP1 output state.

The onboard temperature sensor (TS1) has a digital output at pin 5 (T_{OVER}) which feeds digital input GP2 (pin 4) on IC2. This pin is driven high if the board gets too hot (over 95°C) and IC2 responds by slowly reducing the LED brightness.

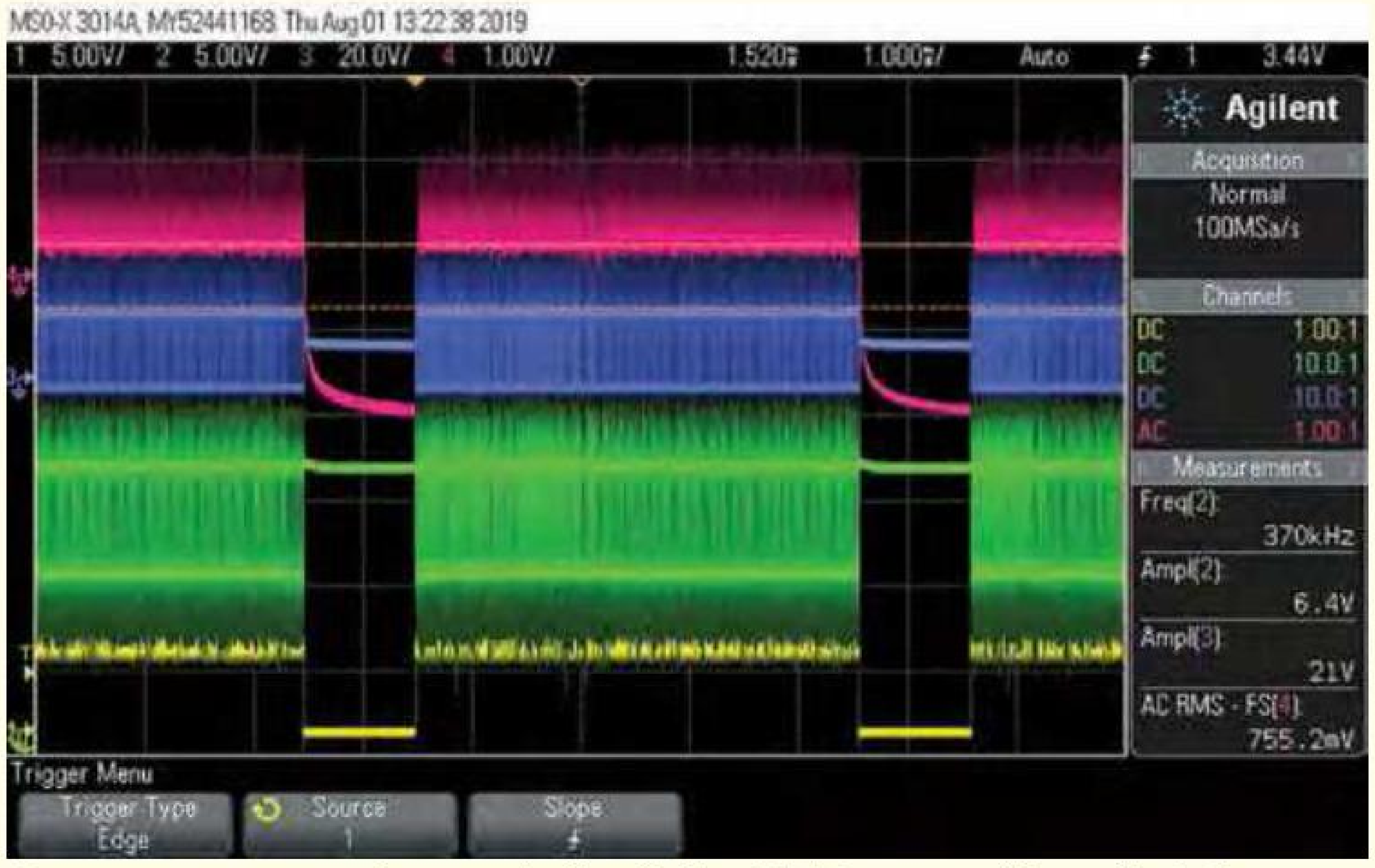
Its pin 3 hysteresis (HYST) input is connected to Vcc to provide 10°C of hysteresis, so when the sensor temperature drops below 85°, pin 5 goes low again, and the LED brightness slowly ramps back up. This prevents damage to the whole unit if operated for long periods at high brightness in hot weather.

If the sensor is at 95°C, the LED array is likely to be well above 100°C, as there will be some distance between them, and no direct path for heat conduction.

The various modes are selected using external momentary pushbutton S1, which connects between GND and the GP0 digital input (pin 1) of IC2. IC2 has an internal pull-up current to keep this pin high when the button is not pressed. It detects when the button is pressed as that pin is then pulled low.


MSO-X 3014A, MY52441168: Thu Aug 01 13:23:23 2019
1 5.00V/ 2 5.00V/ 3 20.0V/ 4 1.00V/
900.0ns 2.000µs/ Stop 1 3.44V
Agilent
Acquisition Normal 100MSa/s
Channels
Measurements
Freq(2): 568kHz
Ampl(2): 6.6V
Ampl(3): 18V
AC RMS - FS(4): 103mV
Trigger Menu
Trigger Type Edge
Source 1
Slope

Scope1: the yellow trace (bottom) is the PWM control signal from pin 3 of IC2 to pin 3 (EN) of IC1, while the green trace above is Q1's gate. The blue trace above that is at Q1's drain while the mauve trace at top is the voltage across the LED array. The time-base for this grab is fast, at 2µs/div, so you can see the switchmode operation at 568kHz, with around 100mV of ripple appearing across the LED.


MSO-X 3014A, MY52441168: Thu Aug 01 13:22:38 2019
1 5.00V/ 2 5.00V/ 3 20.0V/ 4 1.00V/
1.520s 1.000s/ Auto 1 3.44V
Agilent
Acquisition Normal 100MSa/s
Channels
Measurements
Freq(2): 370kHz
Ampl(2): 6.4V
Ampl(3): 21V
AC RMS - FS(4): 755.2mV
Trigger Menu
Trigger Type Edge
Source 1
Slope

Scope2: now we've switched the LED to medium brightness and slowed the time-base to 1ms/div, while keeping the same traces and voltage scaling as in Scope1. You can see that the duty cycle is around 80% and the frequency is 200Hz. When the PWM control signal goes low, the LED drive is cut and the LED filter capacitor discharges until the switchmode driver is re-enabled.

IC2 and TS1 are powered from a 5V rail developed by low-power regulator REG1. This regulator can withstand input voltages up to 30V (it is the limiting factor in this design), can deliver up to 100mA and has a quiescent current of around 1.9mA. As it is not a micropower regulator, an external power switch is recommended to avoid discharging the battery when the light is not in use.

Scope grabs

Scope1-Scope4 below show the voltages at four points in the circuit during different phases of operation. See the captions for an explanation of what each trace represents.

Scope1 Close-up of the switching waveforms, demonstrating how the LED current is regulated. Note how the gate pulses in green all have the same positive width (off-time) while the on-time varies. This is due to switchmode controller IC1 varying the on-time in an attempt to keep the current through the LED at the target level.

Scope2 Shows how the 200Hz PWM brightness control from IC2 causes the LED driver output to switch on and off rapidly, reducing both the light output and power consumption.

Scope3 The same effect but on a lower brightness setting, with a duty cycle of around 40%.

Scope4 Operation of the unit in flashing mode (4Hz), at a much longer time scale, corresponding to a whole second of operation.

Increasing its current delivery

While the ~1A current delivery of this design can give you a really bright light (around 2100 lumens), it is capable of delivering more than twice that with a few minor changes, for a theoretical output of around 5000 lumens, with the right LED(s)!

Replacing the 0.22 0.75W resistor with a same-size 0.1Ω 2/3W resistor will set the average current to around 2.2A. You also need to make the following two substitutions.

Replace D1 with a 3A schottky diode in the same size package, eg, Comchip CDBA340L-G, Diodes Inc B340LA-13-F, On Semi NRVBA340T3G or Micro Commercial SL34A. Replace inductor L1 with Panasonic ETQ-P5M470YFM, with a current rating of 2.9A and a saturation current of 4.1A, in a package about the same size as the specified DR74-330-R inductor.

Two other possible inductor options which are slightly larger are the Murata DD1217AS-H-330M=P3 and Bourns SRN8040TA-330M, both 8 × 8mm. They will be a tight fit on the existing footprint, but it should be possible to solder them to the board without modifications. Both have slightly lower current ratings than the Panasonic part though; adequate, but barely so.

Construction

Fig.3 shows both sides of the assembled board at actual size; it's tiny! The double-sided board is coded 16109191 and measures just 22 × 12mm.

We built our prototype by hand with a regular soldering iron (using a standard chisel tip), so it isn't that difficult, but it definitely requires some skill and patience. IC1 has closely spaced leads (0.5mm apart) while the other parts are not quite so tricky, but are still quite small, so you may need to work under magnification.

The board was designed to be so small to leave as much room as possible to fit the battery in your light housing.

Fig.4(a) shows where the parts go on the top of the board, and it's best to start assembly with this side, specifically, by soldering IC1 in place. As well as having closely spaced leads, this part has a thermal pad on the underside. Ideally, it should be reflow soldered, eg, using a hot-air rework station.

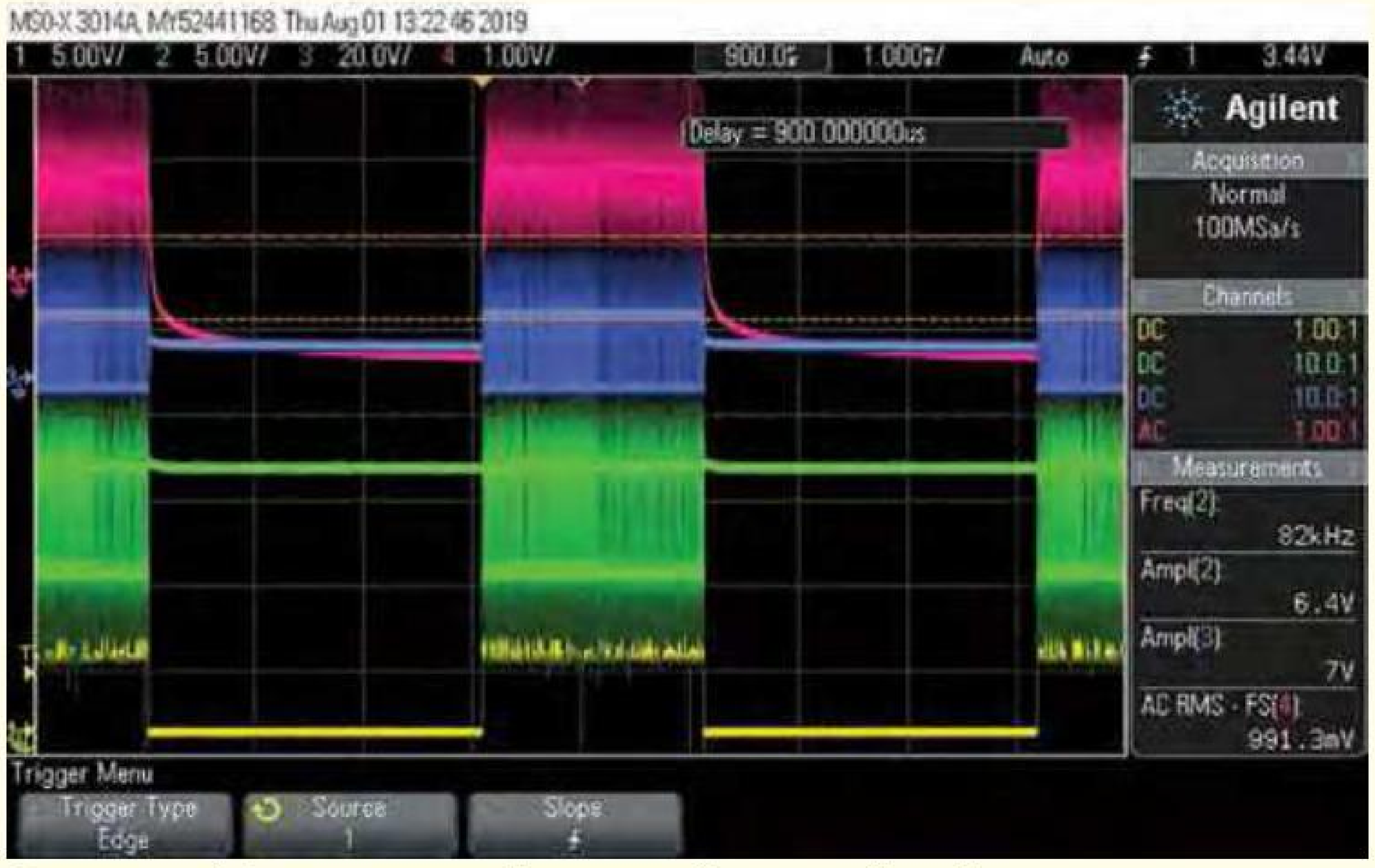
If you have such a station, spread a thin smear of solder paste on all the pads, place the IC in the correct position (ensuring its pin 1 goes towards the nearest corner of the board), then gently heat it with hot air until all the solder reflows. Don't let the hot air dwell too long on one area or you risk burning the PCB or damaging the chip.

The solder under the IC, on the large central pad, is likely to be the last to reflow. But you need to make sure it does, or else you could have hidden short circuits under the chip.

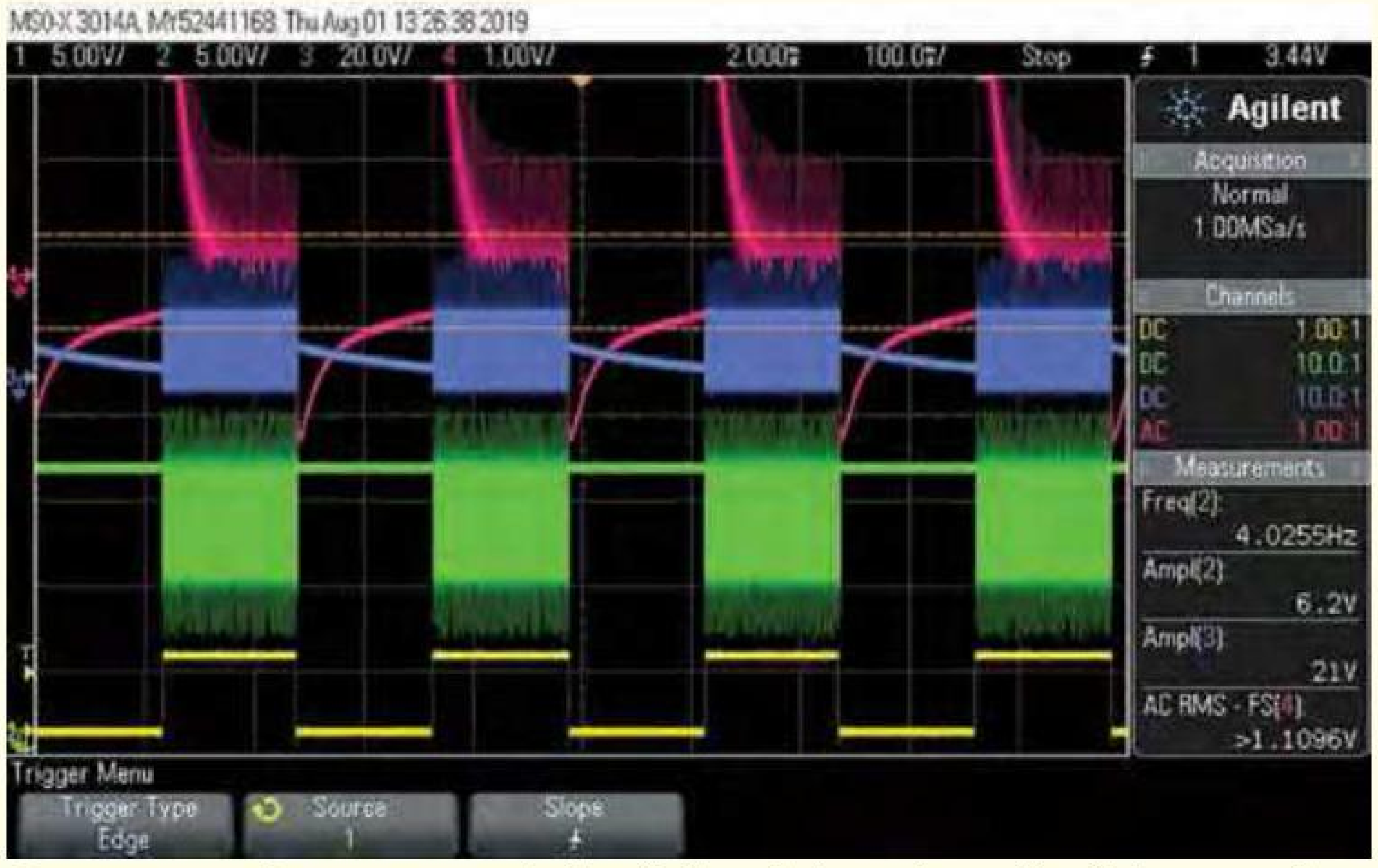
If you don't have a reflow oven or hot air rework station, the PCB pad has been extended slightly past the body of IC1, so that you can still heat the pad directly to solder that thermal pad. You will need a fine-tipped soldering iron to do it this way, though

To hand-solder this chip, add a small amount of solder paste to the middle of the big pad in the middle of its footprint. If you don't have solder paste, spread a thin smear of flux paste over the whole central pad instead. Then locate the pin 1 dot or divot on the IC (using a magnifier) and then rotate it so that it's near the closest corner of the board.

Rotate the whole lot so the that the chip leads are on the left and right sides, then add a tiny bit of solder onto one of the chip's pads (eg, at the upper-right corner if you're right-handed). Heat this solder and gently slide the chip into place.


MSO-X 3014A, MY52441168: Thu Aug 01 13:22:46 2019
1 5.00V/ 2 5.00V/ 3 20.0V/ 4 1.00V/
900.0
1.000
Auto
1 3.44V
Delay = 900.000000us
Agilent
Acquisition
Normal
100MSa/s
Channels
DC 1.00:1
DC 10.0:1
DC 10.0:1
AC 1.00:1
Measurements
Freq(2): 82kHz
Ampl(2): 6.4V
Ampl(3): 7V
AC RMS - FS(4): 991.3mV
Trigger Menu
Trigger Type Edge
Source 1
Slope

Scope3: this scope grab was taken under the same conditions as Scope2, but now the driver is in low brightness mode, with the PWM duty cycle reduced to around 40%.


MSO-X 3014A, MY52441168: Thu Aug 01 13:26:38 2019
1 5.00V/ 2 5.00V/ 3 20.0V/ 4 1.00V/
2.000
100.0
Stop
1 3.44V
Agilent
Acquisition
Normal
1.00MSa/s
Channels
DC 1.00:1
DC 10.0:1
DC 10.0:1
AC 1.00:1
Measurements
Freq(2): 4.0255Hz
Ampl(2): 6.2V
Ampl(3): 21V
AC RMS - FS(4): >1.1096V
Trigger Menu
Trigger Type Edge
Source 1
Slope

Scope4: we've now switched the driver into flashing mode and slowed the timebase down again, to 100ms/div, so that you can see the full effect. The flashing frequency is around 4Hz, and the duty cycle is 50%. Other flashing modes involve switching between lower LED brightness (PWM-controlled) and full brightness.

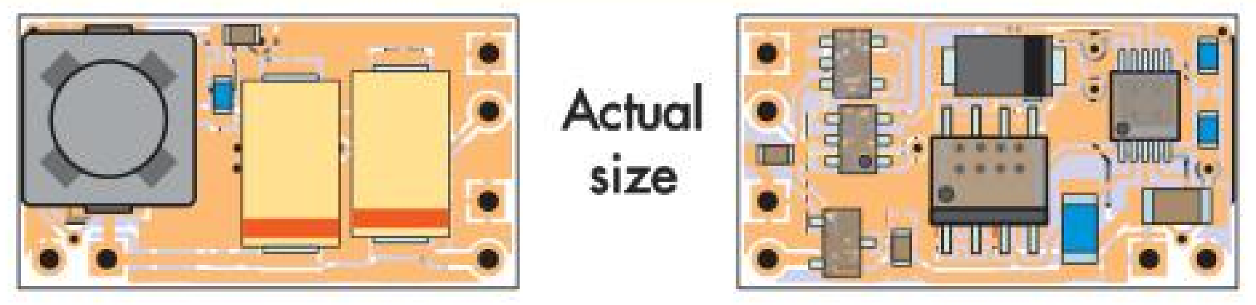


Fig.3: because the PCB is so tiny (same-size diagrams at left) we have also shown the top and bottom at three times the actual size for clarity.

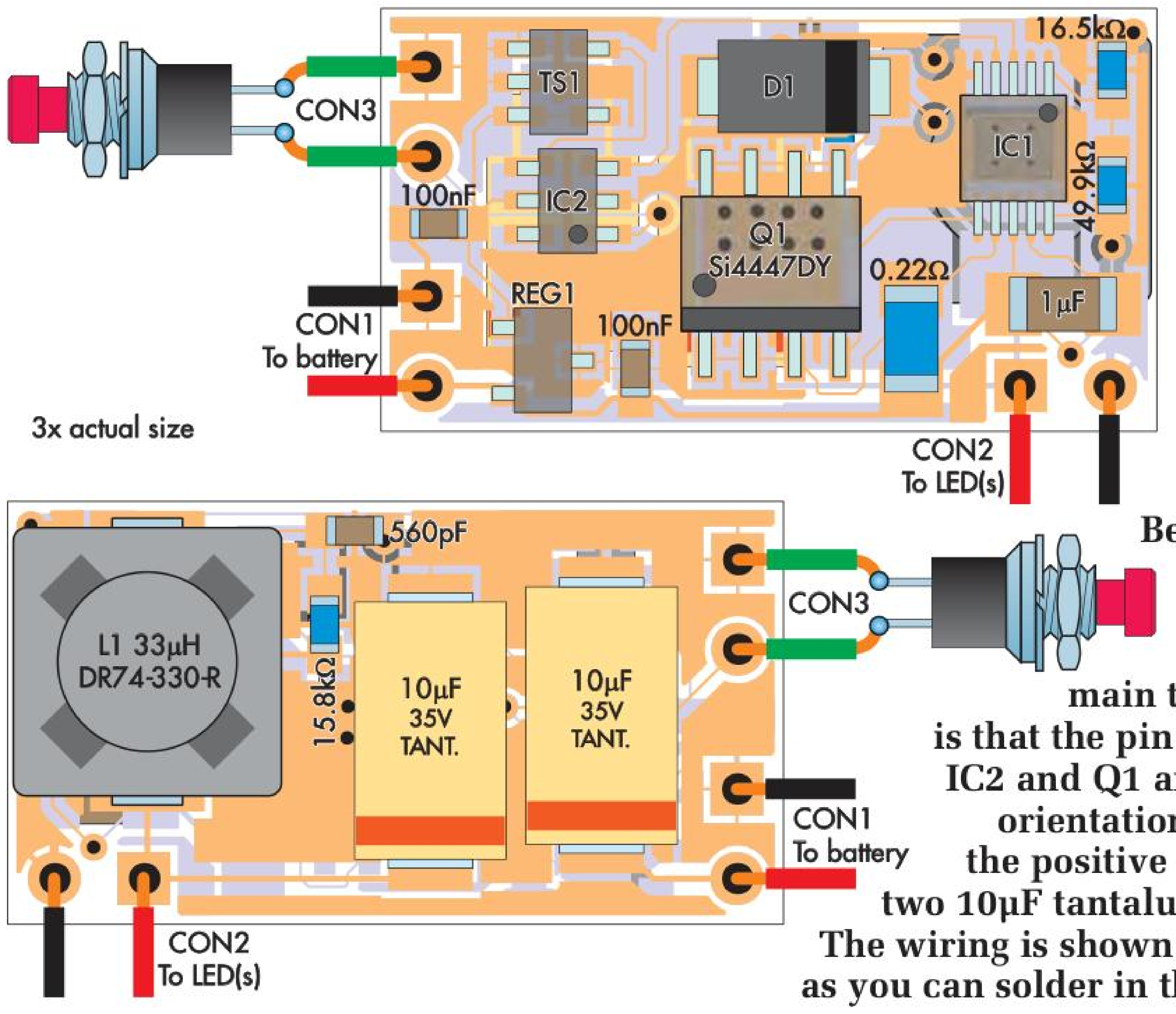


Fig.4: 3x diagrams of the top and bottom of the PCB. Besides making sure all the solder joints are good, the main thing to check is that the pin 1 dots of IC1, IC2 and Q1 are in the right orientations, along with the positive stripes on the two 10µF tantalum capacitors. The wiring is shown on both sides as you can solder in the wires from either side.

Having removed the heat, check to see whether its pins are properly aligned with the pads on both sides. If not, heat that solder joint and very carefully nudge the IC slightly in the right direction.

We got ours very close on our first attempt (probably close enough) but decided to nudge it a few more times to get the alignment perfect. When you're happy, add flux paste to both sides, then add solder to the diagonally opposite pin before drag-soldering the rest of the pins on that side of the chip.

Return to the other side and solder all the remaining pins, including the one you started with. Bridges are hard to avoid; if you get some, add more flux paste, then use solder wick to suck the excess solder off the pins. When you're finished, check them carefully under magnification. You should have nice looking fillets on all pins, down to the pads on the PCB.

Now add a little extra flux paste to the exposed part of the central pad and feed some solder onto it. Hold the heat on there for a few seconds. If you have solder paste under the chip, it should reflow now. Otherwise, the flux paste under the chip should help suck some solder underneath it (fingers crossed).

If you have a hot air rework station, you can still solder the chip by hand, then re-heat it to reflow solder paste underneath the IC. That's what we did, but again, be very careful to ensure that all the solder paste does melt or you will have trouble later. Also, try not to let the airstream blow the chip off its pads! It helps to keep the airflow rate low.

Remaining SMDs

With the tricky part out of the way, solder IC2 next. Ideally, it should be pre-programmed (using 1610919A.HEX code available for downlod frmo thr September 2020 page of the *PE* website). Find its small pin 1 dot and rotate it so that it is facing towards Q1's mounting position. Then use a similar technique as for IC1 to solder it in place. It should be somewhat easier due to having fewer, larger, more widely spaced pins.

Next, fit TS1 and REG1, both of which can only go in one orientation due to the differing number of pins on each side.

Follow with Q1, which has even more widely spaced pins, which can possibly be soldered individually. Ensure its pin 1 dot/divot and chamfered edge go towards the bottom of the board as shown in Fig.3(a).

The PCB is designed to accept a MOSFET in the SOT-669 package, which has a single large tab in place of pins 5-8, so there is one large pad for these pins. There is no need to worry therefore if you bridge them; in fact, we suggest you add enough solder on that side of the device to form one, large solder joint, as we did on our prototype.

There's also no need to worry about bridges between pins 1-3 because these all connect to the same point, but you don't want to bridge pins 3 and 4, as pin 4 is the gate. You can use flux paste and solder wick to clean up a bridge between these pins, should it occur.

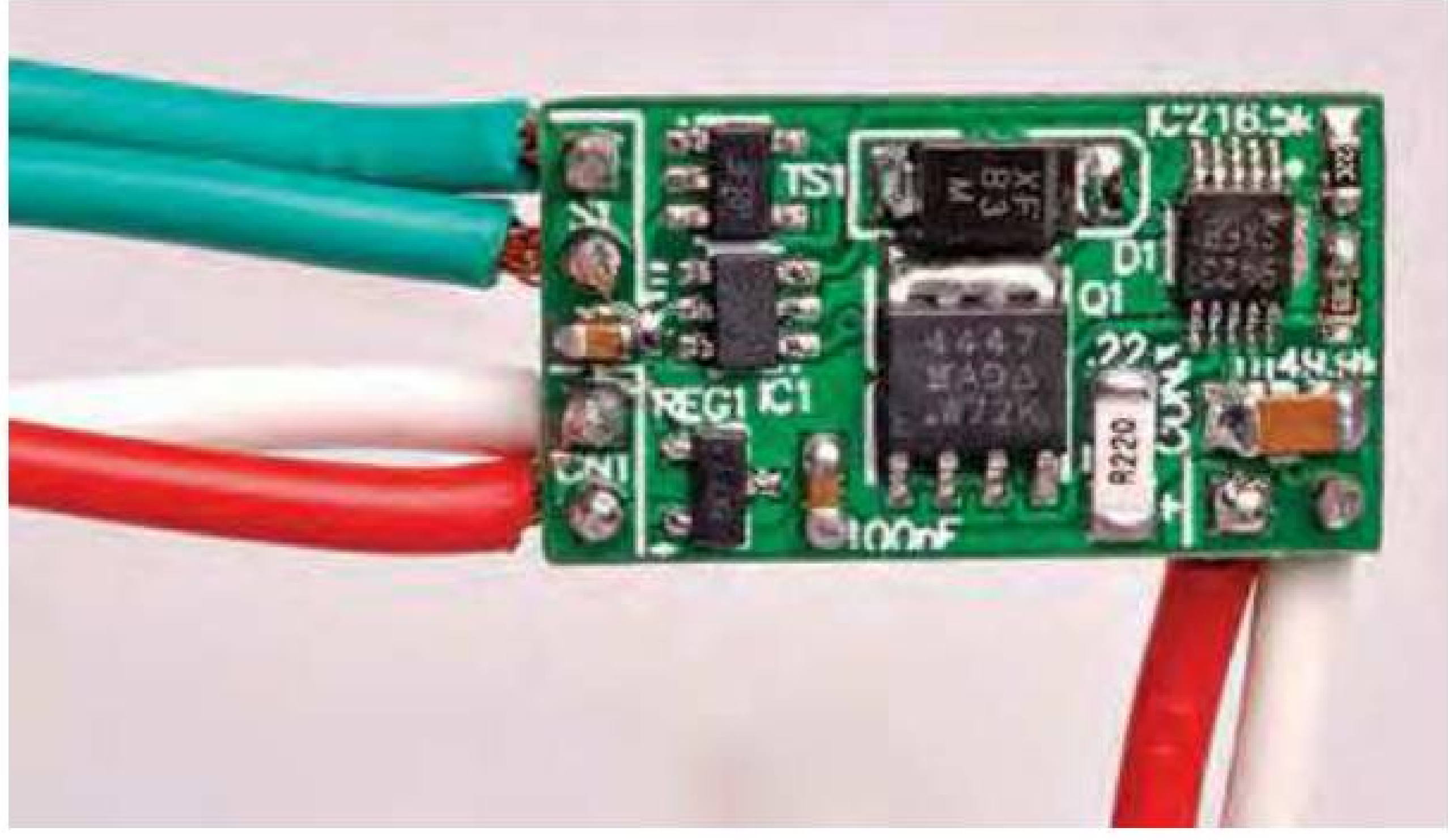
You can now fit diode D1, with its cathode stripe oriented as shown, followed by the three resistors and three capacitors. Make sure you use the correct values for the two smaller resistors.

Components on the other side

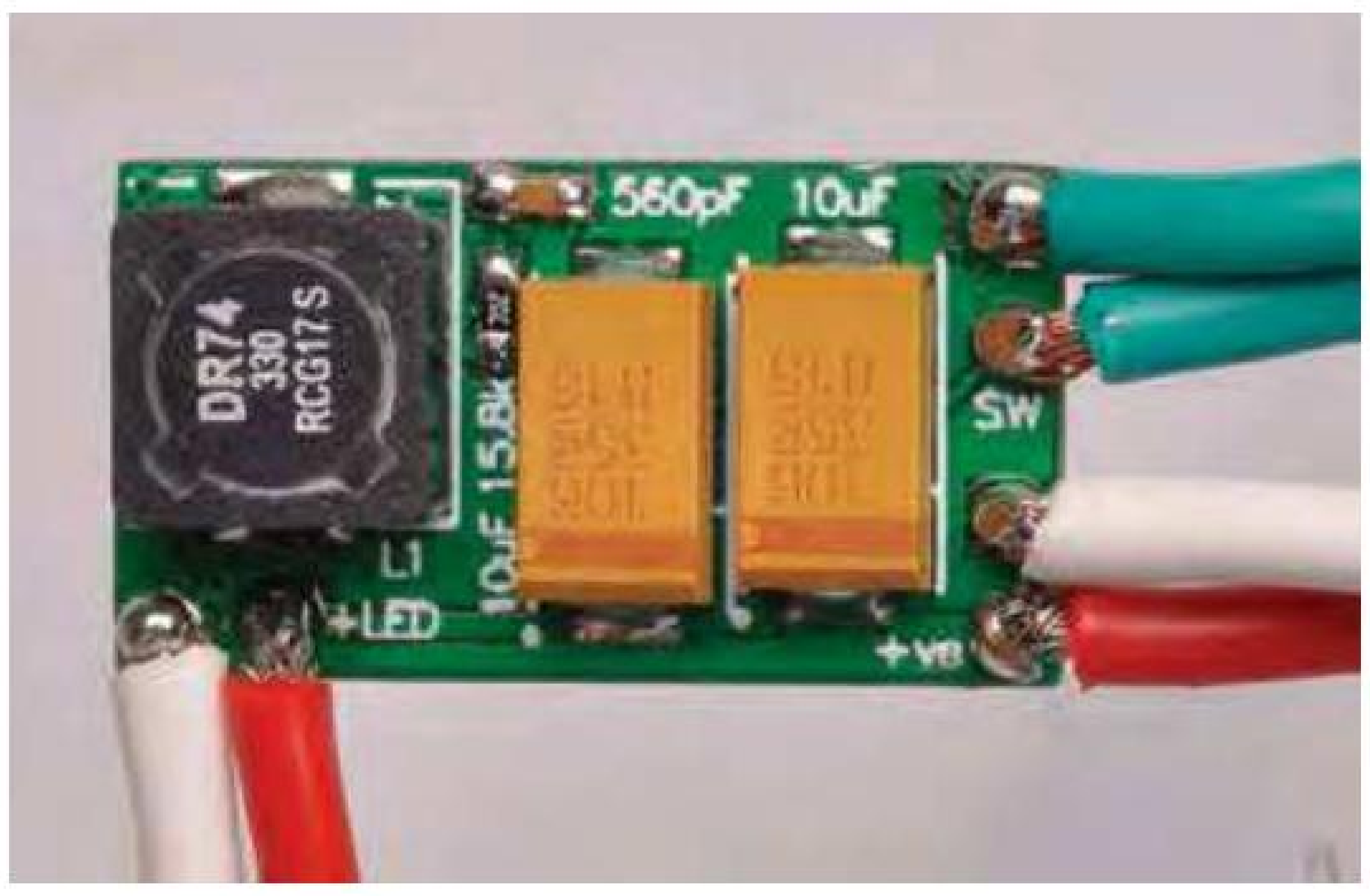
Now flip the board over. There are just five components to mount on this side of the board, as shown in Fig.3(b). Unfortunately, the board will not sit flat at this stage, so you should find some small plastic shims to place strategically under it so that it won't wobble around as you are soldering these final components.

Start with the two smaller components, making sure that you fit the capacitor in the position closer to the board edge. You can then solder the two larger capacitors in place. It helps to have fine tweezers when doing this, as they are quite close together. As usual, make sure the striped ends are oriented correctly.

That just leaves the inductor. Spread some flux paste on its pads, then use the usual technique to tack it into place before soldering the opposite lead. Put some heat



The two sides of the completed PCB are shown here rather significantly oversize, (about twice life size) just so you can see what goes where. The 560pF capacitor, 15.9kΩ resistor, 33µH inductor and the two tantalum capacitors mount on the underside (right) – note the stripes denoting the positive end of the capacitors.



and solder into the joints to make sure the fillets look good on both sides.

Preparing the LED

You may be able to buy a suitable LED pre-assembled and ready to wire up, but the recommended Cree XHP70 LED generally comes as a bare 'chip on board' type LED, which needs to be soldered to a suitable PCB both for electrical connections and to get heat out of it. This is then generally attached to a piece of metal which acts as a heatsink to keep the LED temperature under control.

It's a good idea to then mount the PCB on the back of this heatsink (with a suitable layer of electrical insulation in between!) so that the PCB can sense the heatsink temperature and reduce the LED brightness if it's getting too hot.

But we're getting ahead of ourselves. First, you need to solder the LED to this PCB, which is often in a 'star' shape. Note that the XHP70 can be run at 6V or 12V, depending on the configuration of the PCB, so make sure you get a suitable PCB that's designed to run it at 12V. Otherwise, the LED will require twice as much current for the same brightness.

You can sometimes get the LEDs pre-soldered to the star boards, but we couldn't find one locally, so we ordered the LED and board separately (from **www.cutter.com.au**, but there are plenty of other local/international suppliers).

We then attached the LED to the board. First, we checked the T-shaped marking on the underneath to identify the anodes and cathodes; the bar across the 'top' of the T indicates the cathode. This goes towards the side of the star PCB with the negative (–) pads on it.

We then covered all the LED pads (two small rectangles plug a larger Z-shaped pad) with a thin smear of solder paste mixed with some flux paste, placed the LED on top and gently applied heat from a hot air rework station from underneath the board. We did it this way to avoid overheating and damaging the LED lens. Make sure the small pads on the underside of the LED line up with the two small rectangles on the star board.

We managed to heat the star PCB from underneath by clamping it with a hemostat (self-closing tweezers) and then clamping that in a vice, giving us access to the underside of the board without having to hold it. You definitely don't want to hold an aluminium PCB while heating it to over 200°C! We had to gently nudge the LED using a metal object when the solder reflowed to get it properly centred on its pads. In theory, it should pull itself in due to solder surface tension, but ours got 'hung up' on something and needed some help.

Wiring and testing

The next step is to solder wires to the board for the control pushbutton (S1), battery power and the LED(s). As the board is so small, the wire holes are too, so you aren't going to be able to solder heavy leads to it. You'll be keeping the wires fairly short anyway, so medium-duty hookup wire is adequate.

You will probably need to cut away some of the wire strands at the exposed end, so that you can twist the remaining strands together to fit through the holes in the PCB before soldering them. The current will quickly spread out through the other strands in the wire, so this should not cause any problems. But make sure you don't leave any loose strands that can short to anything else.

Now solder the two LED wires from the board to the '+' and '–' terminals on the LED star, then use screws and thermal paste to attach it to a heatsink. Solder the momentary pushbutton to the end of its wires; its polarity doesn't matter.

Before powering it up, carefully inspect both sides of the board, looking for short circuits between any of the wire solder joints and nearby components, between components or component pins and also to ensure that all pins have good fillets, touching both the pin and the pad.

Parts list – Ultrabrite LED Driver

1 double-sided PCB, code 16109191, 22 × 12mm
1 5S Li-ion/LiPo battery or similar, 1Ah+
1 5S-capable Li-ion/LiPo battery charger
1 2-pin connector to suit battery
1 chassis-mount waterproof momentary pushbutton switch (S1) [eg, Altronics S0960/S0961 or Jaycar SP0756]
1 12V LED array, eg, Cree XHP70.2 P4 bin (2100 lumens at 1A, 4760 lumens at 2.2A)
1 heatsink to suit LED
1 lens to suit LED (optional)
1 DR74-330-R 33µH 1.4A SMD inductor, 7.2 × 7.2mm (L1)
1 waterproof enclosure, large enough for battery and LED(s)
short lengths of medium-duty hookup wire or figure-8

Connector options for battery charging

1 waterproof 4-pin chassis-mount socket [Jaycar PS1009+ PS1005 (10A) or Altronics P9444+P9420 (5A)] ***or***
1 waterproof 6-pin chassis-mount socket [Jaycar PS1003+PS1005 (10A) or Altronics P9446+P9420 (5A)]
1 4-pin line plug [Jaycar PP1006 (10A), Altronics P9474 (5A)] ***or***
1 6-pin line plug [Jaycar PP1000 (10A), Altronics P9476 (5A)]

Semiconductors

1 LM3409MY switchmode LED controller, MSOP-10 (IC1)
1 PIC10F202-E/OT 8-bit microcontroller programmed with 1610919A.HEX, SOT-23-6 (IC2)
1 TC6502P095VCT temperature switch, SOT-23-5 (TS1)
1 LM3480IM3-5.0 high-voltage 5V linear regulator, SOT-23 (REG1)
1 Si4447DY 40V 4.5A P-channel MOSFET, SOIC-8 (Q1)
1 15MQ040 40V 1.5A schottky diode, DO-214AC (D1)

Capacitors

2 10µF 35V SMD tantalum capacitors, low-ESR, D case [eg, Kemet T495D106K035ATE120]
1 1µF 50V X7R SMD ceramic, size 3216/1206
2 100nF 50V X7R SMD ceramics, size 1608/0603
1 560pF 50V X7R SMD ceramic, size 1608/0603

Resistors

(all 1% SMD 1/10W, size 1608/0603 unless otherwise stated)
1 49.9kΩ 1 16.5kΩ 1 15.8kΩ
1 0.22Ω 1% 0.75W, size 3216/1206 [eg, Susumu KRL1632E-C-R220-F-T1]

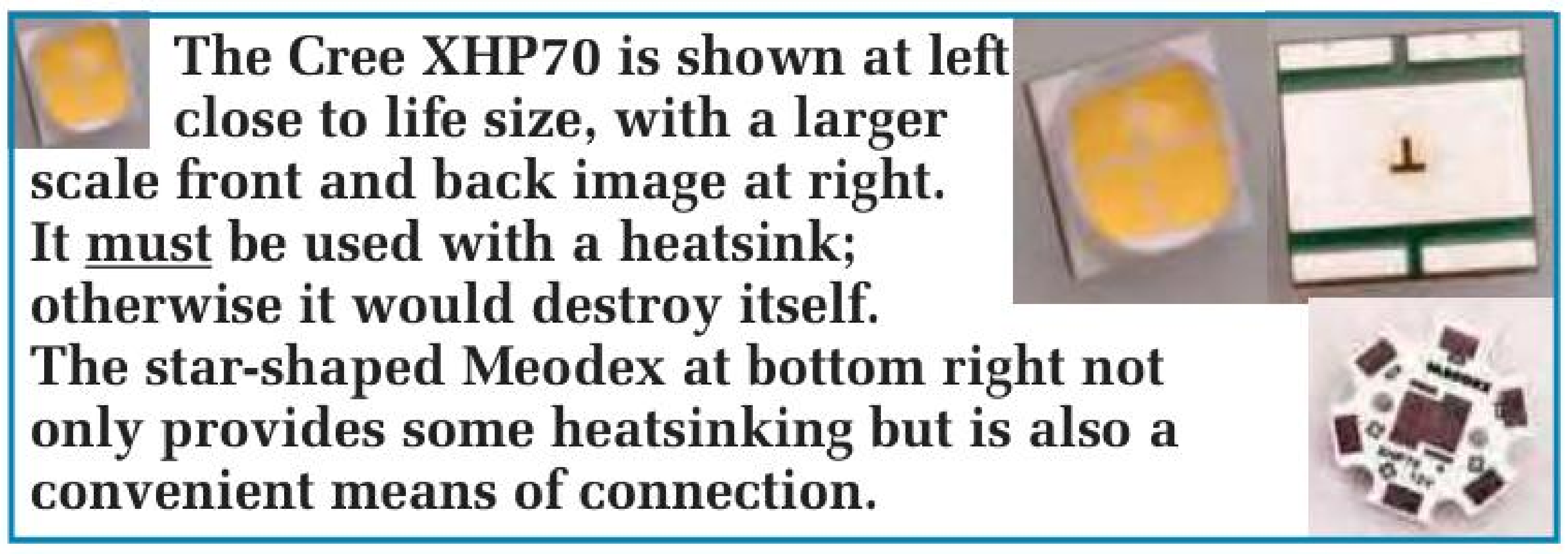
Magnification and good lighting are critical to successfully inspecting a board populated with tiny SMD components. It's also a good idea to clean it thoroughly beforehand, using a specialised flux solvent or alcohol (isopropyl, pure ethanol or methylated spirits). Otherwise, flux residue can get in the way of a proper inspection.

Once you're satisfied that it has been assembled correctly, its time to power it up.

If you have a suitable DC voltage source such as a 15-24V 1A DC plugpack or bench supply, you can now test the unit. Wire up the supply leads and use some electrical tape to make sure they can't short together, then switch on power. At first, nothing should happen. If your supply has a current meter, you should get a reading of no more than a few milliamps.

If the current reading is significantly more than that, switch off and carefully examine your board and wiring for faults.

Now press the pushbutton, and the LED should come on. Depending on the supply voltage, you should see around



The Cree XHP70 is shown at left close to life size, with a larger scale front and back image at right. It must be used with a heatsink; otherwise it would destroy itself. The star-shaped Meodex at bottom right not only provides some heatsinking but is also a convenient means of connection.

500mA being drawn from the supply; slightly less if its output voltage is significantly above 15V. Brief presses of the button again should change the brightness — cycling between medium, low and off.

Holding it down for a few seconds should switch the LED on at full brightness. If you continue to hold it, the LED should start flashing. Once it's flashing, brief presses of the button will change the flashing mode; hold it down for several more seconds to switch the LED off.

If it doesn't work, most likely you have a soldering problem, or one of the components is in the wrong location or was fitted with the wrong orientation. Carefully inspect the board for problems.

If you don't find any, try adding flux paste to all the small IC leads and re-flow them all, either with a soldering iron that has a clean tip or (even better) a gentle application of hot air. Re-test to see if that fixed it.

Once you're sure it's working, switch off the power, disconnect the test supply and solder the battery connector onto the end of the supply wires. Make sure you get the polarity right (very important!) and use heatshrink tubing to insulate the solder joints. There are several common types of lithium-ion battery connector, so you will need to obtain one that matches your battery (usually from the same source).

We've seen connectors with red/black wire colour coding that's actually the opposite of the supply polarity once it's plugged into the battery. So check yours, and if this is the case, use red and black heatshrink tubing to change the wire colours to avoid mistakes.

Placing inside your bike light

At the outset, we designed this project 'tiny', so it could fit inside a bike light. However, because every bike light is different, we can't offer much guidance here.

It may be that you have an old dynamo-type bike light set gathering dust in a cupboard; these have been largely superseded by modern lamps which also save your legs somewhat when pedalling up a hill!

But most of these older-style lights had a fair bit of room inside the light itself (because there was no battery). One of these could be worth experimenting with. The battery will need to be mounted in its own case external to the light – though this could be beneficial when it comes to charging.

We should warn you though that many bike lights (especially plastic ones) may not like the heat of the ultrabright LED, so you may need to come up with some arrangement which ensures your bike light doesn't melt.

Putting it in a case

However, if you need to mount the project in a new case, the following points might help you.

The case should ideally be a waterproof one if you're going to be using it on a bicycle, or anywhere external where it could be in the weather. You will probably have to install a waterproof transparent window so that the LED itself can be mounted inside the box. It can be made from clear plastic and sealed with silicone sealant.

You should also seal around the pushbutton switch to ensure water cannot enter that way. The battery and board should be securely anchored inside the box so that they can't put any strain on the wires.

That just leaves the question of how you charge the battery. You could open the box up and remove the battery to charge it each time it runs low (or just swap it for a fresh one), but that's hardly convenient. To charge the battery without removing it, you will need to fit a waterproof socket to the case and make up a cable with a matching plug to connect to a suitable lithium-ion battery charger.

If you do this, it's vital to choose a connector where you can't accidentally short the pins. That could melt the connector or even damage the battery.

Ideally, multi-cell (series) lithium-ion/LiPo battery packs should be balance charged. In the case of a 5S battery, that requires at least six contacts, two of which will carry the full charging current. But you can get away with the occasional balance charge, so you could compromise by taking the battery out from time to time, and simply fitting a two-pin connector for day-to-day recharges (although some connectors are not available with fewer than four pins).

Another option is to build our April 2017 *Battery Balancer* and mount it inside the case, permanently attached to the battery's balance connector. That way, it will automatically be balanced each time you charge it. It is a relatively small board, so you should not have trouble fitting it, and it draws little current when not active (around 25µA).

We suggest that you use a four-pin chassis-mount socket for regular charging, with the pins wired in pairs for extra current handling, or a six-pin socket for balance charging. Suitable connectors are available from both Jaycar and Altronics; see the parts list for details.

Don't forget to insert the waterproof gasket (if supplied) when putting the lid on your box.

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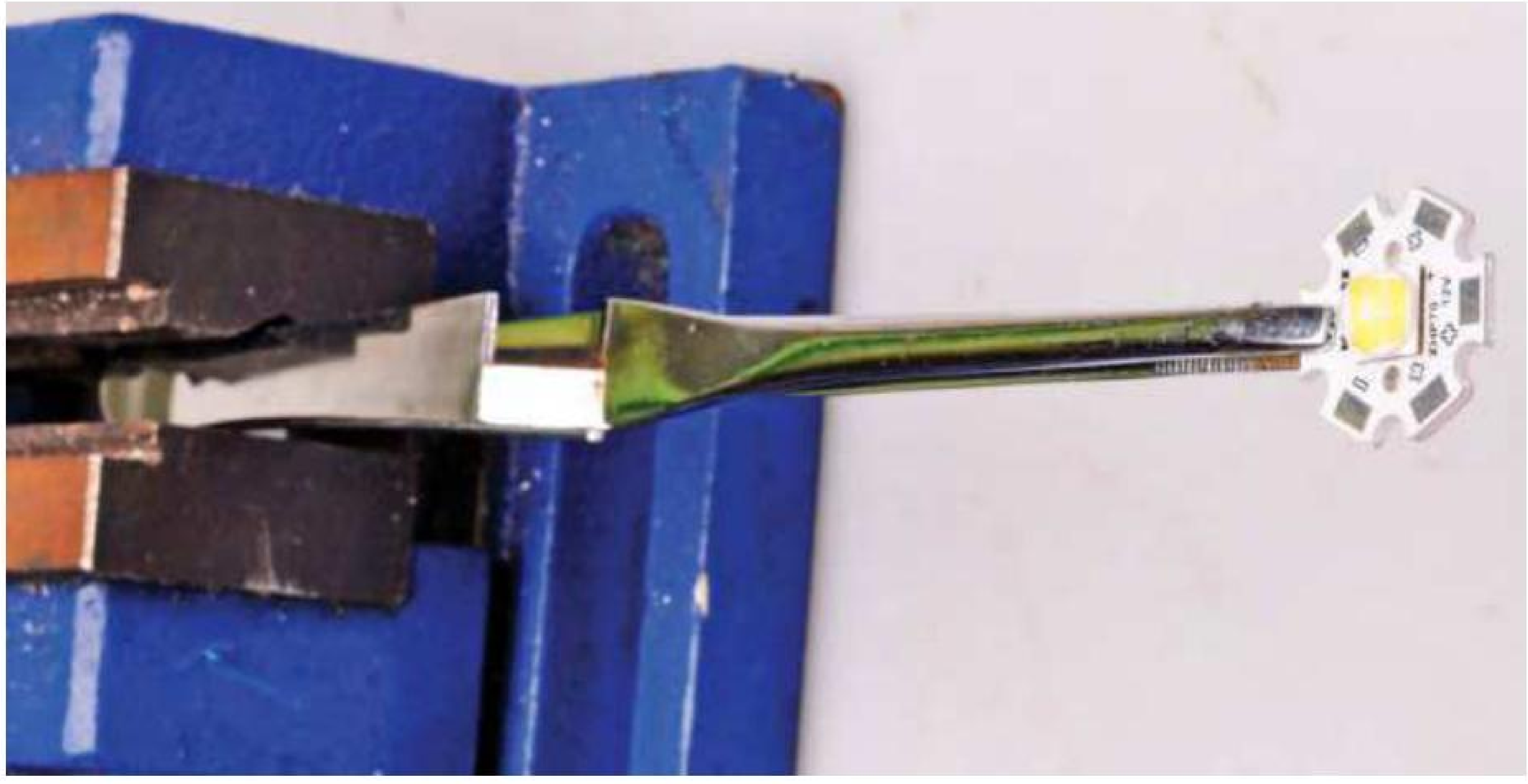

Having trouble holding the LED in place while you solder it? Here's how we did it: a pair of tweezers held tight in a bench vice, with the LED held firmly at the opposite end! A wooden clothes peg (NOT plastic!) also works well!

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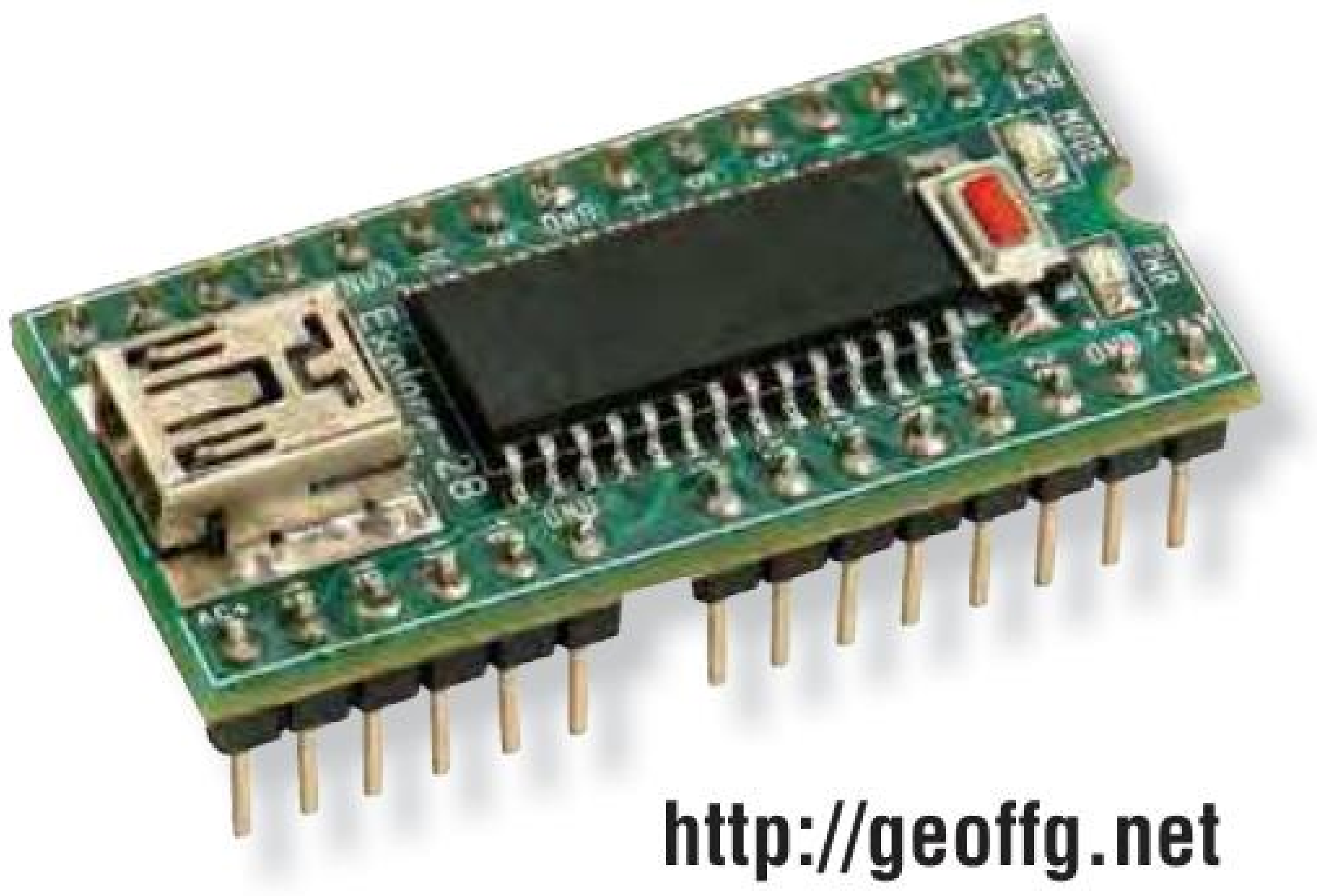
By Geoff Graham

THE MICROMITE EXPLORE-28



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The 28-pin Micromite has been used in many of our projects, and with good reason. It is a low-cost, powerful microcontroller which allows you to create advanced devices with minimal effort. Now the *Explore-28* will make your life even easier. It's a small plug-in module with the same powerful PIC plus a USB socket for comms and programming, giving you everything you need to get started with the Micromite in one handy package.

The Micromite is a high performance 32-bit microcontroller which can be programmed in a friendly BASIC programming language.

It has a lot of built-in capabilities, including a variety of communications protocols (I^{2}C, SPI, serial...), the ability to easily interface to many devices (LCD screens, GPS modules, temperature sensors...). And it's really easy to learn how to use it.

To start with the Micromite, you just need a programmed chip, which you can then plug into a breadboard.

This is not hard to do, but there is a bit of fiddling about to be done before you can start programming the chip. Many readers would prefer a pre-assembled module that can be immediately put to use.

That is the essence of the *Explore-28*. You can plug it into a USB port on your laptop and in a few minutes, have a simple program up and running.

For readers who read the short introductory series *Meet the Mighty Micromite* (February to April 2017) and now follow the *Make it with Micromite* series (from February 2019), the *Explore-28* combines the 28-pin Micromite Mk2 with the *Microbridge* interface (May 2018).

Another way to think about it is that it is a bit like the *Micromite LCD Backpack V2* (May 2018) but without the LCD, and in a much smaller package.

The whole module is only a little bit larger than a 28-pin DIL IC package but it packs a lot of hardware, including:

- A 28-pin Micromite pre-programmed with the latest MMBasic interpreter.
- A USB-to-serial interface, which allows you to plug the *Explore-28* into your computer and immediately start programming.
- A PIC32 programmer, so that you can update the BASIC interpreter whenever a new version is released.
- A power supply with a 4-16V input range and the ability to supply up to 150mA at 3.3V (plus 5V, when powered from USB) for external circuitry.

This means that if you purchase a pre-assembled *Explore-28* module, you can immediately start experimenting with it. You do not need to source the microcontroller, program the firmware or setup a breadboard. It is a fully assembled and ready-to-go package.

It is interesting to compare the *Explore-28* to the Commodore 64 from 1982, which also came with a built-in BASIC interpreter and was the most popular computer in the 1980s. Many millions were sold worldwide, for around US $600 each.

The *Explore-28* is fifty times faster, with much more memory and costs about US $20. While they clearly have different end uses, this still illustrates how far modern semiconductor technology has progressed.

The *Explore-28* printed circuit board and concept was developed by two Micromite enthusiasts in New Zealand: Graeme Rixon and Robert Rozee. It can be purchased as a kit of parts or as a completely assembled module from **micromite.org** or Graeme's website – see the last page of this article for details.

Graeme Rixon also offers a full construction pack, which you can download from his website. This includes the PCB Gerber files, parts list and firmware.

So, you can get your own PCBs made and build your *Explore-28* modules from scratch if you wish.

Connections

The *Explore-28* has the same 'form factor' as the Arduino Nano, which means that breakout boards designed for the Nano will suit the *Explore-28*. But the two are quite different in a programming sense; the Micromite is vastly more powerful and is programmed in BASIC, not C/C++.

The pin-out of the *Explore-28* is shown in Fig.1. Essentially, it mimics the pins on the 28-pin DIP version of the Micromite, except pin 20 which is not present. The module also includes two extra pins at the bottom, labelled +5V, which can be used to feed power in or out.

Explore-28 features

- Complete microcontroller module with USB interface and power supply
- Programmed in BASIC, with 60KB program space and 50KB RAM for variables
- 19 I/O pins with 10 capable of being used as analogue inputs
- Supports communications protocols including async serial, I^{2}C, SPI and Dallas OneWire
- Support for special devices such as temperature sensors, keypads, IR remote controls
- Full support for touch-sensitive LCD panels up to 3.6-inch (9.2cm) diagonal
- Embedded controller features such as sleep, control over clock speed and watchdog timer
- Built-in PIC32 programmer for updating the firmware
- Runs from 4-16V @ 50mA
- Compact size: 40mm long, 19mm wide and 8mm tall (without header pins)

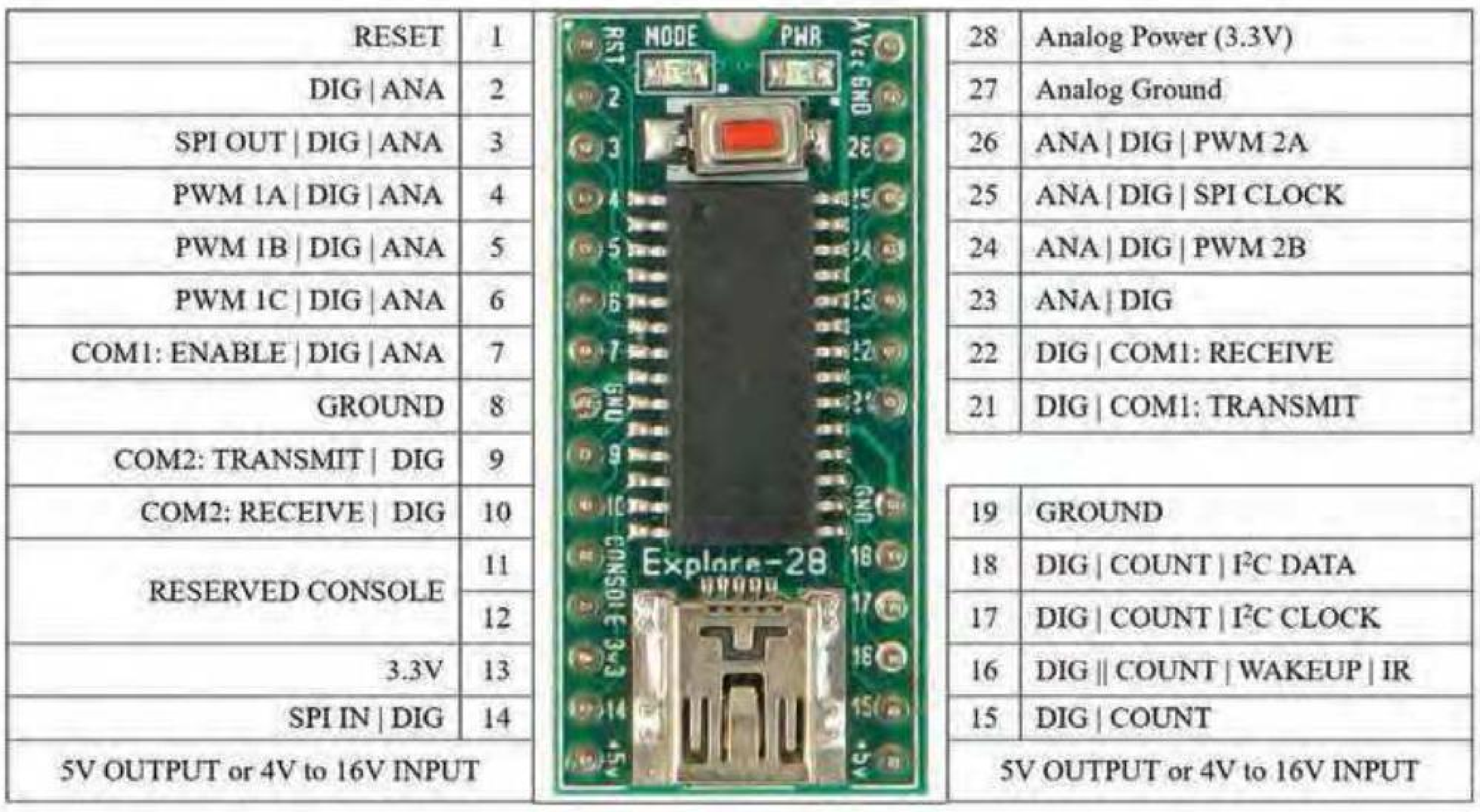

RESET 1
DIG | ANA 2
SPI OUT | DIG | ANA 3
PWM 1A | DIG | ANA 4
PWM 1B | DIG | ANA 5
PWM 1C | DIG | ANA 6
COM1: ENABLE | DIG | ANA 7
GROUND 8
COM2: TRANSMIT | DIG 9
COM2: RECEIVE | DIG 10
RESERVED CONSOLE 11 12
3.3V 13
SPI IN | DIG 14
5V OUTPUT or 4V to 16V INPUT
28 Analog Power (3.3V)
27 Analog Ground
26 ANA | DIG | PWM 2A
25 ANA | DIG | SPI CLOCK
24 ANA | DIG | PWM 2B
23 ANA | DIG
22 DIG | COM1: RECEIVE
21 DIG | COM1: TRANSMIT
19 GROUND
18 DIG | COUNT | I²C DATA
17 DIG | COUNT | I²C CLOCK
16 DIG || COUNT | WAKEUP | IR
15 DIG | COUNT
5V OUTPUT or 4V to 16V INPUT
MODE
PWR
Explore-28

Fig.1: the *Explore-28* has 19 I/O pins, with 10 that can be used as analogue inputs. Other connections include a 3.3V output, ground and two pins which can be a 5V output or external power input (4-16V). ANA means analogue I/O capable, DIG means digital. The other notations refer to the special capabilities of each pin – see the *Micromite User Manual* for a full description.

When the *Explore-28* is plugged into a USB port, it will power itself from the USB 5V supply, and that voltage appears on the +5V pins. This is useful if you want to power some other devices from 5V.

You can also power the *Explore-28* by connecting an external power source to either of the 5V pins. The input can range from 4V to 16V. For example, you could power the *Explore-28* from a 12V battery.

But note that if you are using an external power source, you cannot plug the *Explore-28* into your computer's USB port at the same time. The two power supplies will conflict and possibly damage your USB port or computer.

Second, if you are powering the *Explore-28* from a car battery, you will need to include extra circuitry to protect it from the excessive voltage spikes that can be found in an automotive electrical system.

The Micromite chip itself requires a 3.3V supply, and this is provided by the onboard regulator. This voltage is made available on pin 13 so that you can power external components that require 3.3V.

Up to 150mA can be drawn from this pin; however, you will need to make sure that this does not cause the regulator to overheat and shut down (particularly with high input voltages).

USB/serial interface

The *Explore-28* includes a PIC16F1455 microcontroller, which is programmed to act as both a USB-to-serial interface and also as a PIC32 programmer (used for updating the Micromite firmware).

This is called the *Microbridge* and when it is acting as a USB-to-serial interface, it creates a virtual serial port on your computer. This acts like a normal serial port, but it works over USB.

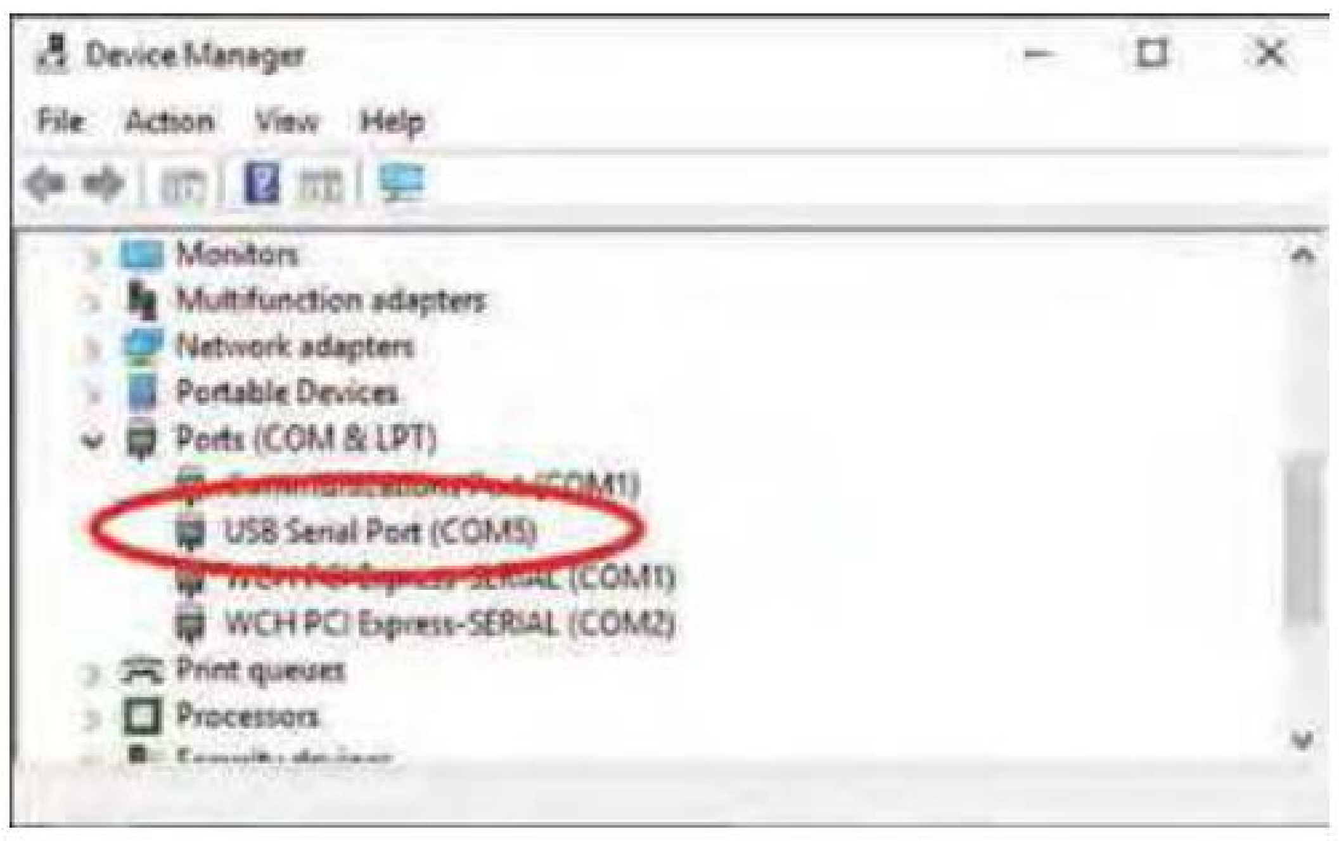
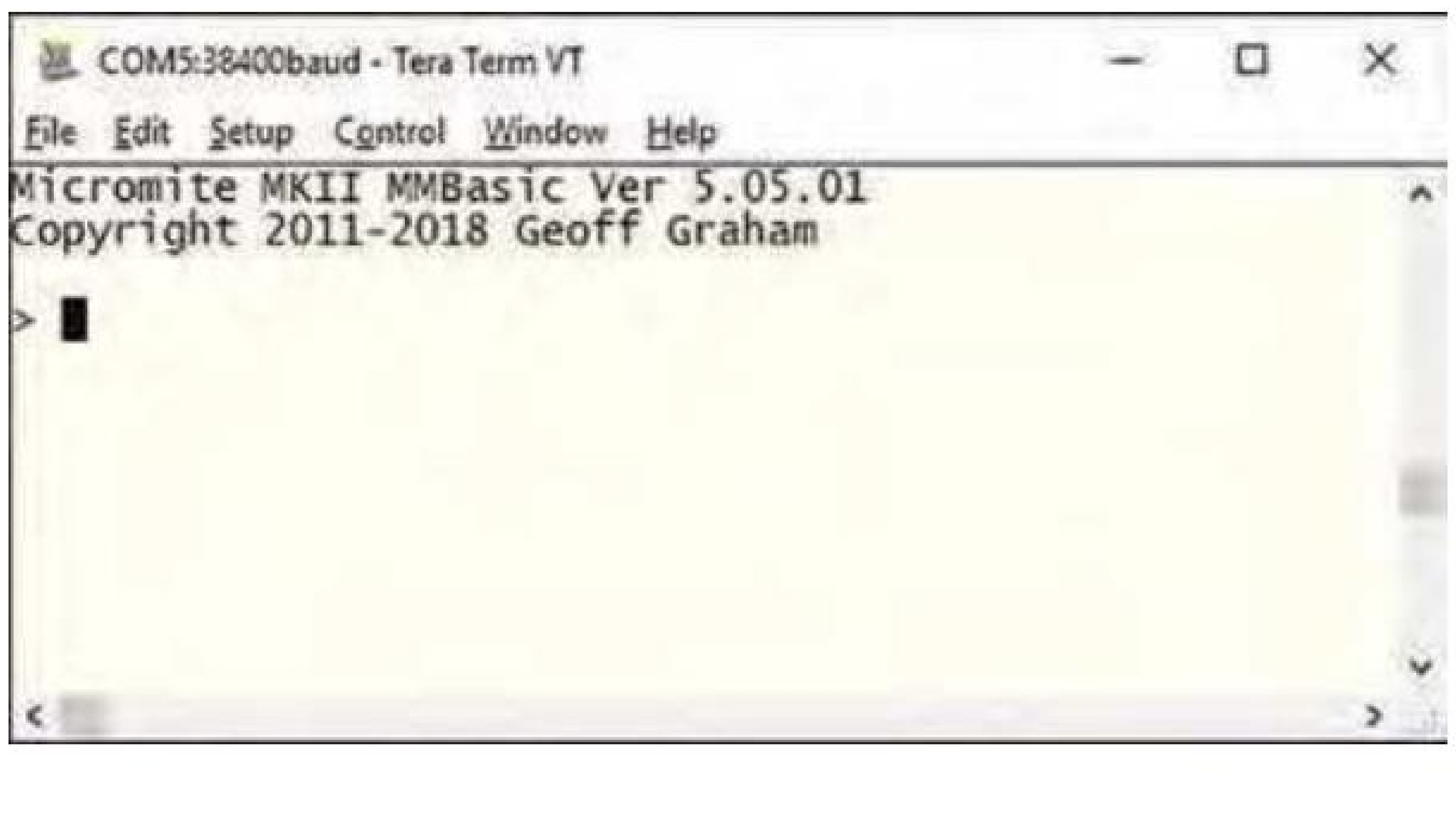

Device Manager
File Action View Help
Monitors
Multifunction adapters
Network adapters
Portable Devices
Ports (COM & LPT)
Communications Port (COM1)
USB Serial Port (COM5)
WCH PCI Express-SERIAL (COM1)
WCH PCI Express-SERIAL (COM2)
Print queues
Processors

Fig.2: when the *Explore-28* is plugged into a Windows computer, it is allocated a virtual serial port number by the operating system. You can check what COM number was allocated by going into Device Manager and looking for a new device listed under Serial Ports (it is COM5 in this example).


COM5:38400baud - Tera Term VT
File Edit Setup Control Window Help

```
Micromite MKII MMBasic Ver 5.05.01
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> 
```

Fig.3: when you have connected to the virtual serial port created by the *Explore-28*, you will see the MMBasic command prompt ('>'), as shown here. At this point, you can try out commands, set options, enter programs and run them.

As mentioned above, we introduced the *Microbridge* in the May 2018 issue of *PE*, and it is used in the later versions of the *Micromite LCD Backpack* (for V2, see May 2018; and V3 in August 2020).

The *Microbridge* connects your computer to the Micromite's serial console. This is the main programming interface to the Micromite, and you can use it to set options, enter programs, run them, get feedback from running programs and also receive data.

If you're running Windows, it will automatically create a virtual serial interface when the *Explore-28* is plugged into a USB socket on your computer. This appears as a COM port, usually with a high number such as COM5 or COM21.

On Windows 7 and earlier versions, a device driver may be required (see **https://bit.ly/pe-sep20-win7**), but Windows 8 and 10 already have the driver built in.

You can check the COM number that Windows allocated to the *Explore-28* by going into Device Manager and looking for a new device listed under Serial Ports, as illustrated in Fig.2.

The Linux kernel and macOS operating systems usually do not need any special configuration and, as an example, under Linux Mint, the *Explore-28* normally appears as: /dev/ttyACM0.

Accessing the Micromite console

When you plug the *Explore-28* into your computer, the LED marked 'PWR' (LED1) will illuminate, to show that it is powered.

To access the Micromite's console, you need to run a terminal emulator on your computer.

This takes the key presses that you make and sends them down the serial interface to the Micromite, while also displaying any responses from the Micromite.

For Windows, you have several choices. We recommend Tera Term (**http://tera-term.en.lo4d.com/**), but there are many other terminal emulators to choose from, with some specially written for the Micromite (see the *Micromite resources* panel).

The Micromite's console defaults to a speed of 38,400 baud, so all you need to do is configure your terminal emulator for the correct COM port number and this baud rate.

Then, when you press Enter, you should see the Micromite command prompt (a greater than symbol: '>'), as shown in Fig.3.

At this point, you have full control of the Micromite for entering commands or setting options.

You can experiment by typing `PRINT 1/7` and pressing Enter. The

The Mighty Micromite

The Micromite is based on the Microchip PIC32, which is a high-performance 32-bit microcontroller. While this chip as supplied is powerful, it is not that easy to write programs for it (the manuals run to over a thousand pages!) and the standard programming languages used on it are assembler, C or C++. These languages and the programming software are complex and require experience to use properly.

For the average hobbyist, the Micromite firmware makes programming much easier. It's loaded into the Flash memory of the PIC32 and turns the chip into a Micromite. The Micromite firmware insulates you from the complexities of the underlying silicon, while still allowing you to use its features.

To program the Micromite, you use the BASIC programming language, which is designed to be easy for beginners and allows you to get started almost immediately.

The BASIC language

The following is an elementary introduction to Micromite programming. We published a comprehensive three-part series on using the Micromite in the February to April 2017 issues, so refer to those articles for more detailed instruction. Plus of course the ongoing Make it with Micromite series.

The Micromite version of BASIC is called MMBasic (short for MicroMite BASIC) which is loosely based on the Microsoft BASIC interpreter that was popular years ago. 'Interpreted' means that the firmware reads through your program line-by-line, executing each command as it finds them.

BASIC (an acronym for **B**eginner's **A**ll-purpose **S**ymbolic **I**nstruction **C**ode) was initially developed by Dartmouth College in the US for teaching programming, and therefore emphasises ease of use. BASIC is also a powerful language, and it became popular in the 1980s and 90s with the introduction of small computers such as the Commodore 64 and Apple II. These days, it is still used in some large commercial data systems (usually running Pick Basic).

BASIC program execution starts at the top of the program and continues until it runs off the bottom or hits an `END` command. Generally, there is one command per line, although you can have more if you wish, each separated by the colon (`:`) character.

A command can be something like `PRINT` which will output some text to the console, `PIN()` which will set the state of an output pin, or `SERVO` which will control a servo motor.

Decisions within the program are made using the `IF`…`THEN` command. So, for example, your program can include something like:

```
IF t > 30 THEN PRINT “too high”
```

Your program can also run commands in loops. For example, the following will display the numbers from one to ten:

```
FOR nbr = 1 to 10
 PRINT nbr
NEXT nbr
```

Micromite input/output

The Micromite is intended to be a controller that can be embedded in something like a burglar alarm or process controller. In this type of role, its ability to use the I/O pins to control external devices is critical.

An I/O pin refers to the physical pin on the Micromite chip. On the Explore-28, these are routed to pin headers on the edge of the module, with the same numbering.

So, when you refer to a pin number in your program, that is both the physical pin on the chip and the pin header number.

In MMBasic, you configure an I/O pin on the chip using the `SETPIN` command – it defines the pin as a digital input, digital output or analogue input. For example, if pin 2 on the chip has been defined as an analogue input, the function PIN(2) will read the voltage on pin number 2; eg:

`PRINT PIN(2)` would create a simple voltmeter.

To read the state of a pin configured as a digital input, you use the same function, but in that case, it will return zero for a low voltage and one for voltage high. You can set the output level of a pin configured as a digital output by assigning a value to `PIN()`. For example, this will set the output on pin 24 to a logic high (3.3V):

```
PIN(24) = 1
```

There are many other things that you can do with the Micromite's I/O pins, including measuring frequency, timing, generating square waves and more.

Special device support

A great feature of the Micromite is that it has built-in support for many external devices like temperature and humidity sensors, keypads, real-time clocks and servos. For example, using the `IR` command, you can receive commands from an infrared remote control.

This is easy to do, and it adds flair (and utility) to your project when you can control it by pressing a button on a remote control.

As another example, you can connect a low-cost ultrasonic distance sensor to the Micromite and with one function, read the distance to an object in centimetres.

Measuring temperature and humidity is just as easy; MMBasic will query the sensor for you and return the temperature in degrees Celsius and humidity in %RH.

Perhaps the most outstanding feature of the Micromite is its ability to control a touch-sensitive LCD panel. The Micromite can display text and graphics and respond to touch inputs on the panel's face.

Communications protocols

There are many modules and chips that you can buy to measure anything from air quality to acceleration. These all send their data via some communication protocol, usually serial, and the Micromite supports four main protocols:

- Asynchronous serial, which is used by computers, lab equipment and GPS modules.
- I^{2}C, which is used by gas sensors, real-time clocks and many other chips.
- SPI, which is used, for example, by accelerometers, memory chips and electronic compasses.
- Dallas One-Wire, which is mostly used for temperature sensors.

GPS modules are particularly valuable; they're cheap (£8-20) and give you your precise location, altitude, speed, heading and the exact time.

Using the Micromite's serial interface, it is easy to retrieve this information and they open up a world of exciting projects that can be built.

Micromite will return the result of dividing 1 by 7, then display the command prompt again.

This is called 'command mode' and it allows you to try out most BASIC commands at the command prompt. It is handy for testing commands while you are learning the language.

Note that when you type something on the console or the Micromite sends some data to your PC, the LED marked 'MODE' (LED2) will briefly flash to indicate that data is being sent over the virtual serial port.

The tactile pushbutton near the LEDs (switch S1) is used to put the *Microbridge* into its programming mode (more about that later).

A handy feature of the *Microbridge* is that you can reset the chip by sending a break signal over the virtual serial interface. In Tera Term, this is done by pressing `ALT-B`, and this has the same effect as cycling the power to the Micromite.

Programming example

We mentioned how easy it is to get started with the *Explore-28*, so here is a short tutorial to illustrate that point.For a beginner, the best method of entering a program into the Micromite is to use the Micromite's built-in full-screen editor.

This is fully documented in the *Micromite User Manual*, but to get started, all you need to know is that the arrow keys on your keyboard will move the cursor around the text and the backspace key will delete the character before the cursor.

At the command prompt, type `EDIT` followed by the `Enter` key. This will take you into the Micromite's editor. Then, enter this short program:

```
SETPIN 15, DOUT
DO
  PIN(15) = 1
  PAUSE 500
  PIN(15) = 0
  PAUSE 500
LOOP
```

To save this program, press the `F1` key or `CTRL–Q` (which does the same thing). This will return you to the command prompt. Then, to run the program, type `RUN` and press `Enter`.

This program toggles the voltage on pin 15 of the *Explore-28* from zero to 3.3V and then back again every second, and continues doing it forever. You can test this by probing pin 15 with a voltmeter, and you should see the voltage jumping up and down at 1Hz.

While the program is running, you will not see the command prompt in the terminal emulator. This is because the Micromite is now busy, but you can regain control by pressing `CTRL–C`.

This is the break key and it will interrupt any running program and return control to the command prompt, so that you can edit the program or enter other commands.

Circuit description

The circuit of the *Explore-28* is shown in Fig.4. As you can see, it isn't terribly complex. It consists of three main components: IC1, the 28-pin PIC32 microcontroller (the Micromite); IC2, the PIC16F1455 (*Microbridge*) which provides the USB interface; and a voltage regulator to provide the 3.3V supply (REG1).

The PIC32 used for the Micromite (IC1) is in a 28-pin surface-mounting package, with most of its pins going directly to the header pins on the edge of the board (CON1-CON3). The 10µF capacitor on pin 20 is critical and must be a high-quality multilayer ceramic type. It is used to stabilise the chip's internal 1.8V regulator, and if it is missing or the wrong type is used, the Micromite will not work.

The only Micromite pins which do not go directly to a corresponding pin on CON1-CON3 are: pin 11, the serial data out line, which goes via a 1.5kΩ resistor in order to protect IC1 if an external device attempts to drive it above +3.3V or below 0V (eg, a raw RS-232 signal); and pin 20 (VCAP), as this micro pin is already connected to the required capacitor.

Several of the micro's pins also connect to the *Microbridge* (IC2), to allow the *Microbridge* to reprogram the chip and for its USB/serial function. As mentioned earlier, the *Microbridge* chip has two functions; it acts as a USB-to-serial bridge and as a PIC32 programmer.

On power-up, it starts in the USB-to-serial bridge mode, with the MODE LED (LED2) off, except for flickering when there is serial activity. Serial data is transmitted from pin 6, which connects to the receive data pin (pin 12) on IC1.

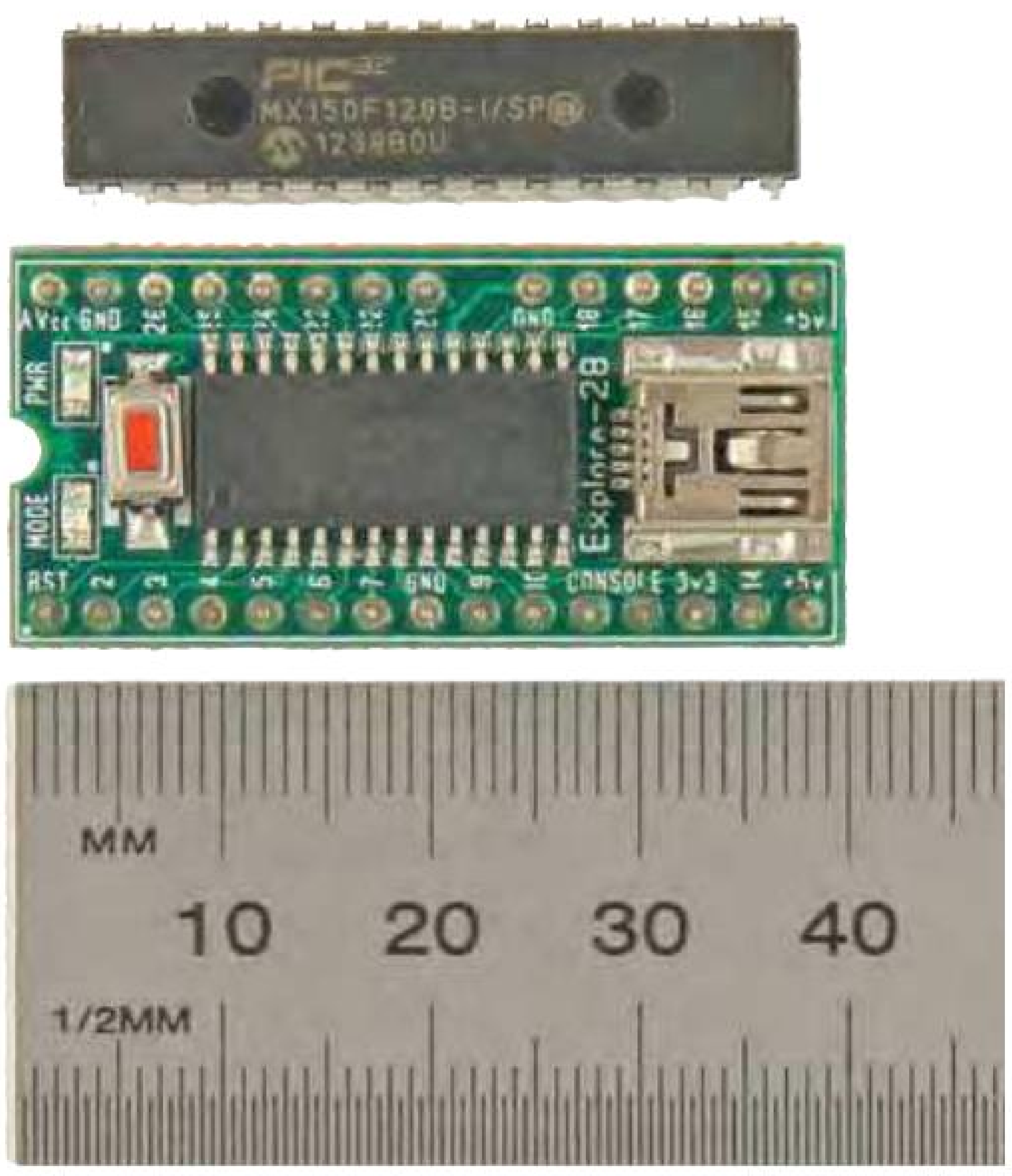
Similarly, the Micromite's transmit pin (pin 11) connects to receive (pin 5) on the *Microbridge* chip.

A second 1.5kΩ resistor between the TX pin of IC2 (pin 6) and the RX pin of IC1 (in 12) protects IC2 in case external circuitry tries to send data to the Micromite while the *Microbridge* is active.

A 10kΩ pull-up resistor from 3.3V to pin 11 of IC1 prevents glitches on the serial port when the Micromite is reset. Another 10kΩ pull-up resistor on pin 1 ($\overline{\text{MCLR}}$) prevents spurious resets of the chip.

The tactile switch on pin 4 of IC2 is used to place the *Microbridge* into its PIC32 programming mode. In this mode, the MODE LED (LED2) lights up, and the *Microbridge* chip uses pin 7 to reset the PIC32 and pins 2 and 3 to drive its programming interface.

In normal operation, these pins are in a high-impedance state, so the corresponding I/O pins on the Micromite can be used for other purposes.



The *Explore-28* is just a little larger than the original 28-pin Micromite in a standard dual inline plastic (DIP) package. But it has many more features, including a USB-to-serial interface, onboard PIC32 programmer and a 3.3V regulator.

Parts list – Micromite Explore-28

1 four-layer PCB coded 07108191, 39 × 18.5mm
1 15-pin male header, 2.54mm pitch (CON1)
1 6-pin and 8-pin male header, 2.54mm pitch (CON2,CON3) (optional)
1 mini type-B SMD USB socket (CON4) [Altronics P1308, element14 2300434]
1 mini SMD tactile pushbutton switch (S1) [element14 1629616]

Semiconductors
1 PIC32MX170F256B-50I/SO microcontroller programmed with MMBasic, SOIC-28 (IC1)
1 PIC16F1455-I/SL microcontroller programmed for Microbridge, SOIC-14 (IC2)
1 MCP1703A-3302E/DB low-dropout 3.3V regulator, SOT-223 (REG1)
2 red SMD LEDs, 2012/0805-size (LED1,LED2)

Capacitors (all SMD 2012/0805 ceramic)
1 10µF 6.3V X5R
2 4.7µF 16V X5R
2 100nF 50V X7R

Resistors (all 1% SMD 2012/0805)
2 10kΩ *(Code 103)*
4 1.5kΩ *(Code 152)*
1 10Ω *(Code 100)*

The power supply is based on a low-dropout linear regulator (REG1; Microchip MCP1703) with a fixed output of 3.3V.

This powers both the *Microbridge* chip (IC2) and the Micromite (IC1) and as mentioned, is also made available on pin 13 of CON1 for external circuitry to use. The MCP1703 can source up to 250mA, with about 50mA of that being used by the *Microbridge* and the Micromite.

Besides the critical 10µF capacitor described above, there are two 100nF bypass capacitors for the 3.3V supplies of IC1 and IC2, plus 4.7µF input bypassing and output filtering ceramic capacitors for REG1.

PIC32 programmer

We mentioned above that the *Microbridge* chip can act as a PIC32 programmer for loading firmware updates into the Micromite (IC1).

You essentially get this feature for free, which is handy, as previously you needed to purchase a separate PIC32 programmer to take advantage of new releases of the Micromite firmware.

If you purchased the *Explore-28* as a fully assembled module or a kit, both microcontrollers (the PIC32 and PIC16F1455) will be supplied pre-programmed, so this programming feature is only required if you want to update the firmware with a new release.

The process of loading new firmware into the Micromite is painless and only takes a minute or two. Start by switching the *Microbridge* into its programming mode and then, using free software on your laptop, you upload the new firmware via USB to the *Microbridge*, which in turn programs it into the flash memory of the Micromite.

To enter into the programming mode, momentarily press the tactile switch on the *Explore-28*. The *Microbridge* chip will then immediately switch to its PIC32 programming mode, and the MODE LED will illuminate to confirm this. If you did not intend to enter this mode, you can revert to the USB-to-serial mode by simply cycling the power.

The software you need to reprogram the Micromite is called **pic32prog**. The Windows version is available from the September 2020 page of the *PE* website, while the macOS and Linux versions are available from other sites.

The Windows version does not need to be installed; you can copy the executable to a convenient location and start a command window in that folder.

New versions of the Micromite firmware can be found at the author's website, **http://geoffg.net/micromite.html** (scroll to the bottom of the page). The Micromite firmware download on the *PE* website is also updated periodically, but there may be a delay between a new release and it appearing on our website.

Generally, the firmware is contained in a .zip file, along with the Micromite manuals, so you need to unzip its contents and locate the firmware file (it has a .hex extension). Then, copy this file to the same folder as the **pic32prog** program.

Programming the firmware

To program this file into the Micromite chip, run **pic32prog** with the following arguments:

```
pic32prog -d ascii:comxx
  yyyy.hex
```

Here, `xx` is the COM port number and `yyyy.hex` is the name of the firmware file. The COM port number is the same as that allocated by Windows when the *Microbridge* was in its USB-to-serial converter mode.

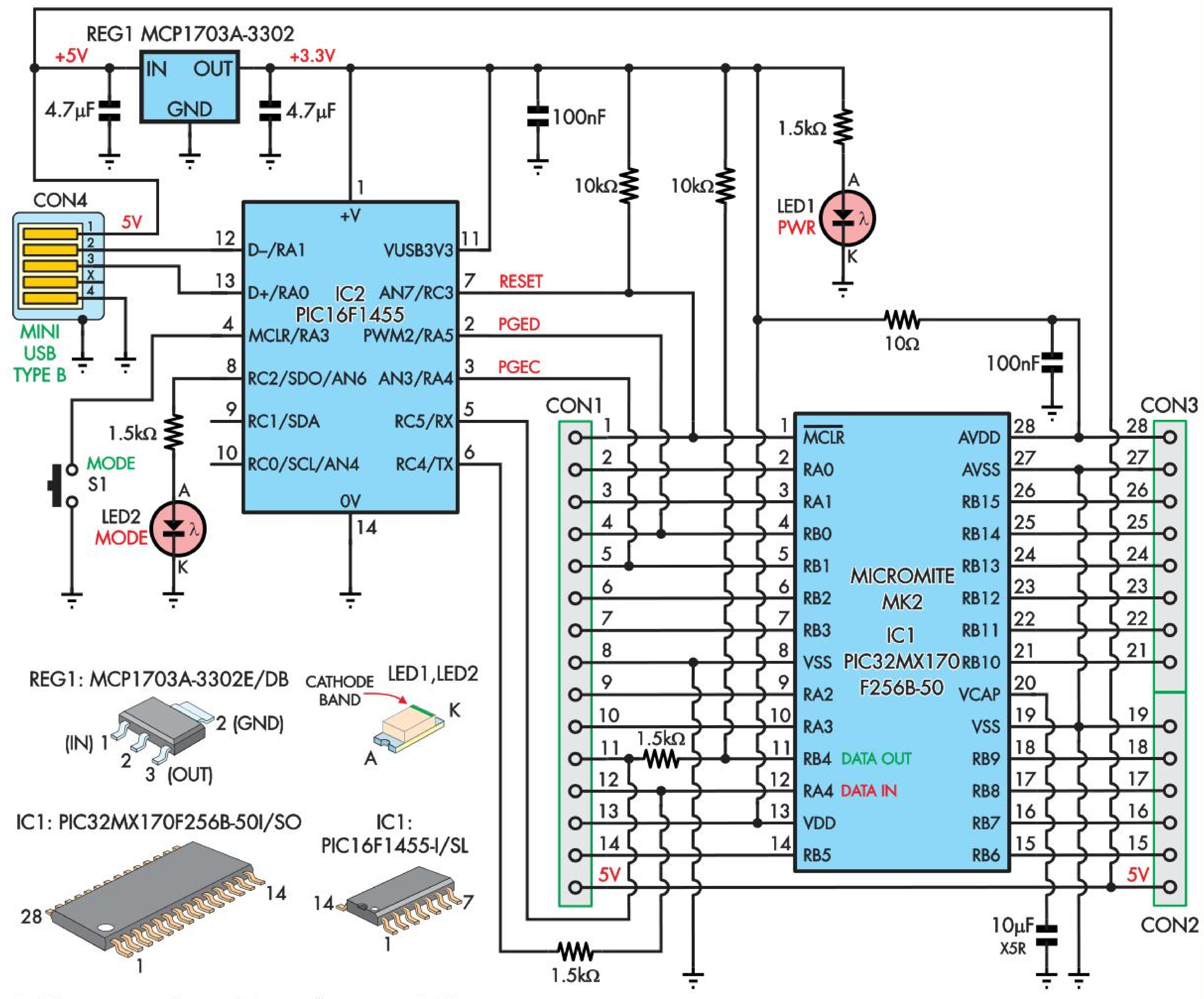
As an example, if your *Microbridge* was allocated the virtual serial port of COM23 and the file that you wanted to program was **Micromite_V5.05.09.hex**, the command would be:

```
pic32prog -d ascii:com23
  Micromite_V5.05.09.hex
```

Before you do this, make sure that you have closed the terminal emulator that you were previously using to communicate with the *Microbridge* in its USB-to-serial mode. Not doing this is a common mistake and it will cause **pic32prog** to abort with an error message, because it cannot open the virtual serial port.

When you press enter at the end of this command, **pic32prog** will upload the hex file to the *Microbridge*, program it into the PIC32, then read back the programmed data to verify that the programming operation was executed correctly. The whole operation will take less than a minute and sample output of the whole process is shown in Fig.5.

After the programming operation, the MODE LED will switch off, the *Microbridge* will revert to operating as a USB-to-serial converter, and the Micromite will automatically restart with the new firmware.



REG1 MCP1703A-3302
+5V
+3.3V
IN
OUT
GND
4.7µF
4.7µF
100nF
10kΩ
10kΩ
1.5kΩ
LED1 PWR
A
K
λ
CON4
5V
1
2
3
X
4
MINI USB TYPE B
+V
D–/RA1
VUSB3V3
D+/RA0
IC2
PIC16F1455
AN7/RC3
MCLR/RA3
PWM2/RA5
RC2/SDO/AN6
AN3/RA4
RC1/SDA
RC5/RX
RC0/SCL/AN4
RC4/TX
0V
RESET
PGED
PGEC
10Ω
100nF
1.5kΩ
MODE
S1
LED2 MODE
CON1
CON3
CON2
MCLR
RA0
RA1
RB0
RB1
RB2
RB3
VSS
RA2
RA3
RB4
DATA OUT
RA4
DATA IN
VDD
RB5
AVDD
AVSS
RB15
RB14
RB13
RB12
RB11
RB10
VCAP
VSS
RB9
RB8
RB7
RB6
MICROMITE MK2
IC1
PIC32MX170 F256B-50
10µF X5R
1.5kΩ
1.5kΩ
REG1: MCP1703A-3302E/DB
2 (GND)
(IN) 1
2
3 (OUT)
CATHODE BAND
LED1,LED2
K
A
IC1: PIC32MX170F256B-50I/SO
IC1: PIC16F1455-I/SL
28
14
1
14
7
1

Micromite Explore 28

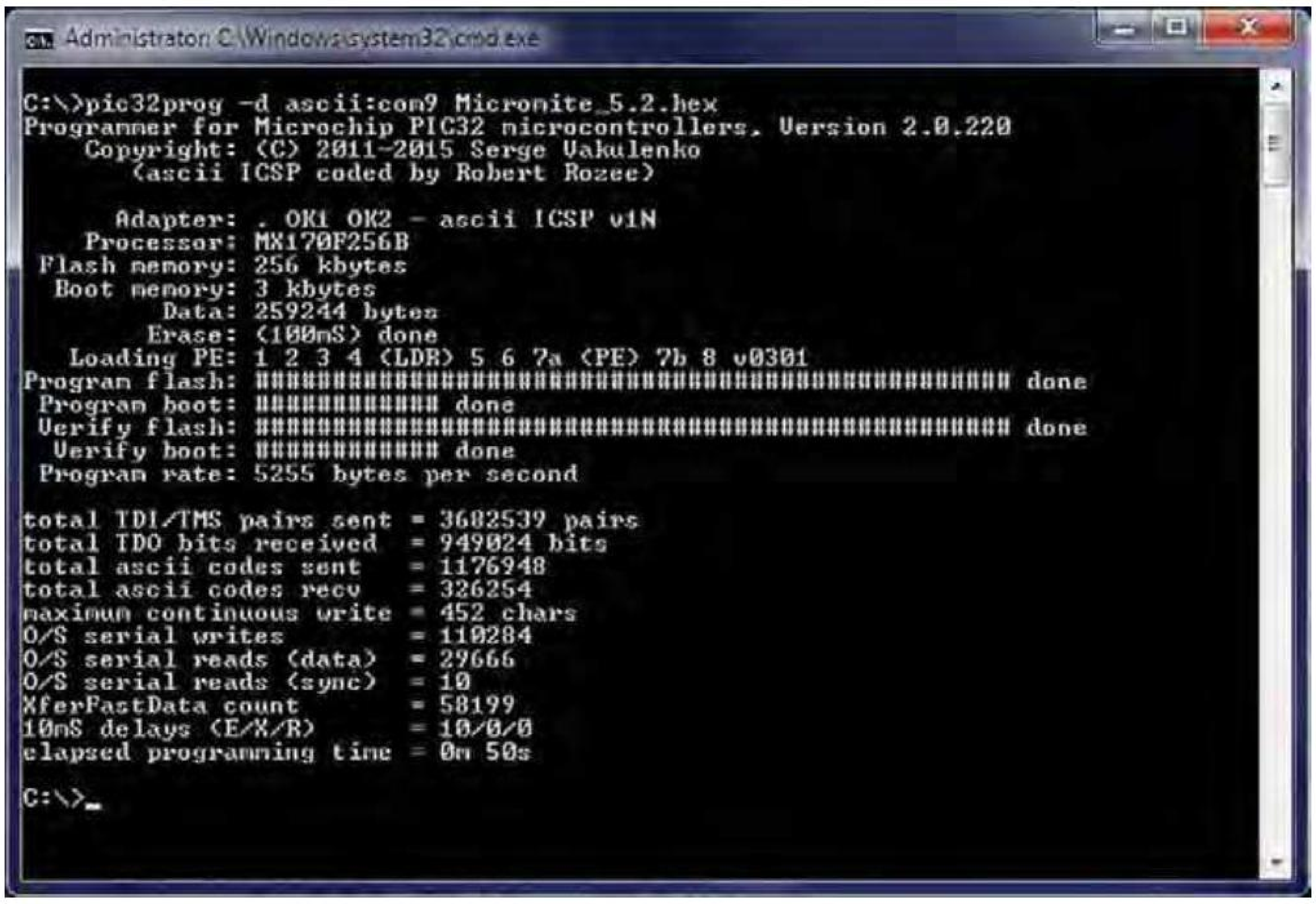
Fig.4: the circuit of the *Explore-28* module is elegant in its simplicity. IC1 is the PIC32 which runs MMBasic; IC2 is the Microbridge which provides a USB serial port and the ability to reprogram IC1; and REG1 is a low-dropout regulator which provides both ICs with a 3.3V supply rail, derived from USB 5V or a source of 4-16V DC fed in via CON1 and/or CON2.

Updating the Micromite's firmware will reset any options set and completely erase the BASIC program memory. So make sure that you make a copy of the program stored on the Micromite before starting the upgrade.

Construction

Because the *Explore-28* is readily available as an assembled module, we expect that many readers will take that option. However, if you decide to assemble your own module, you will find that it is not hard but you will need a steady hand and ideally, some experience soldering surface-mount components, even though the ones used in this project are not that small (at least, by SMD standards).

We have often covered soldering surface mounted components before, and using them is nothing to be feared. The secret is to use plenty of flux paste and keep only a small amount of solder on the soldering iron's tip. The flux makes the solder flow smoothly around the joint while using only a minimal amount of solder means that you will avoid solder bridges and blobs.



```
C:\>pic32prog -d ascii:com9 Micromite_5.2.hex
Programmer for Microchip PIC32 microcontrollers. Version 2.0.220
    Copyright: (C) 2011-2015 Serge Vakulenko
      (ascii ICSP coded by Robert Rozee)

      Adapter: . OK1 OK2 - ascii ICSP v1N
    Processor: MX170F256B
 Flash memory: 256 kbytes
  Boot memory: 3 kbytes
         Data: 259244 bytes
        Erase: (100mS) done
   Loading PE: 1 2 3 4 (LDR) 5 6 7a (PE) 7b 8 v0301
Program flash: ################################################## done
 Program boot: ############ done
 Verify flash: ################################################## done
  Verify boot: ############ done
 Program rate: 5255 bytes per second

total TDI/TMS pairs sent = 3682539 pairs
total TDO bits received  = 949024 bits
total ascii codes sent   = 1176948
total ascii codes recv   = 326254
maximum continuous write = 452 chars
O/S serial writes        = 110284
O/S serial reads (data)  = 29666
O/S serial reads (sync)  = 10
XferFastData count       = 58199
10mS delays (E/X/R)      = 10/0/0
elapsed programming time = 0m 50s

C:\>_
```

Fig.5: the typical output from pic32prog after it has programmed a new version of the MMBasic firmware into the Micromite using the Microbridge. The whole operation is straight forward and takes less than a minute.

The PCB used for the *Explore-28* is a four-layer board, coded 07108191, measures 39 × 18.5mm, and has components mounted on both sides. It is available from the *PE PCB Service*.

The overlay diagrams, Figs.6(a) and (b), show where the components are mounted, along with top and bottom layer tracks.

We haven't shown the two inner layers because that would make the diagrams hard to read. The outer layer tracks shown are used for signal routing, while the two inner layers consist of a ground plane and a power (+3.3V) plane.

These cover most of the board and only have holes where vias pass between the top and bottom layers.

Other vias are used to connect these planes to component pins.

While Fig.6 shows where all the components need to be mounted, the silk screen printing on the board will also guide you during assembly.

It's best to solder the SMD components on the bottom side first (the side with IC2 and REG1), then add the components to the top side, and finish with the pin headers.

Before soldering IC2, if you haven't purchased a pre-programmed kit, you need to program it with the *Microbridge* firmware. This can be downloaded from the *PE* website or from: **http://geoffg.net/microbridge.html** (scroll to the bottom of the page).

You will also need a narrow SOIC programming socket to do this, so unless you have one, you're better off acquiring a programmed chip.

You do not need to program the PIC32 microcontroller used for the Micromite because the *Microbridge* will do that for you when you have finished construction.

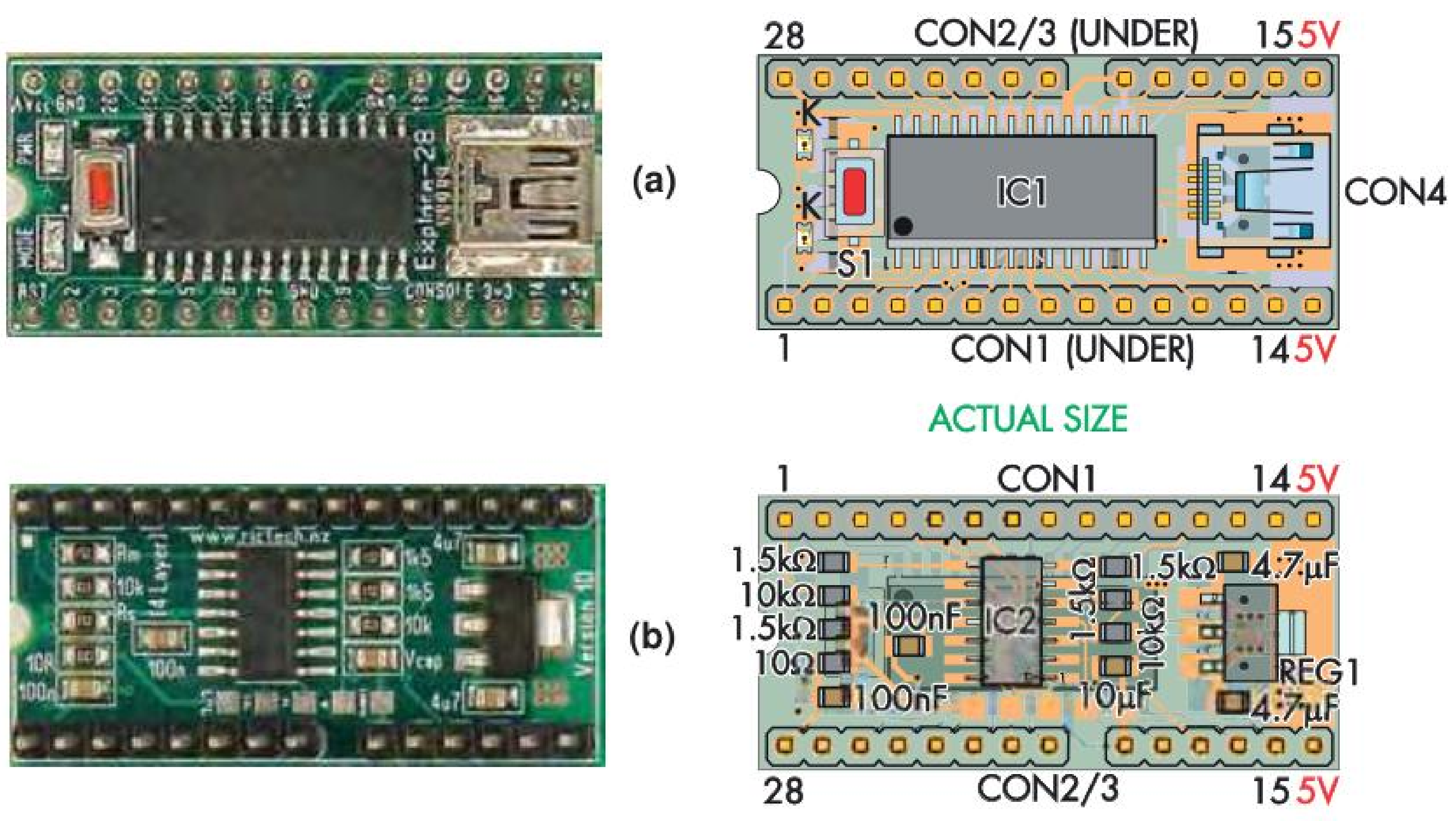
Solder IC2 on the bottom side of the board first, taking care that its pin 1 dot is oriented towards the nearby empty square pads, as shown in Fig.6.

If you bridge two pins with solder, clean up the bridge by applying a little flux paste and then solder wick.

Follow with REG1, which can only go in one way around. It's best to apply a little flux paste to the large pad first, then solder the three smaller pins before finishing with the large tab. You may need to turn your iron up to get a good solder joint on the tab.

Now add the seven resistors and five capacitors to the bottom side, being careful not get any of the different values mixed up.

Flip the board over and then solder the USB socket. Make sure its five signal pins line up correctly with the pads (aided by the two plastic posts going into holes on the board), then solder those signal pins and ensure there are no bridges between them.



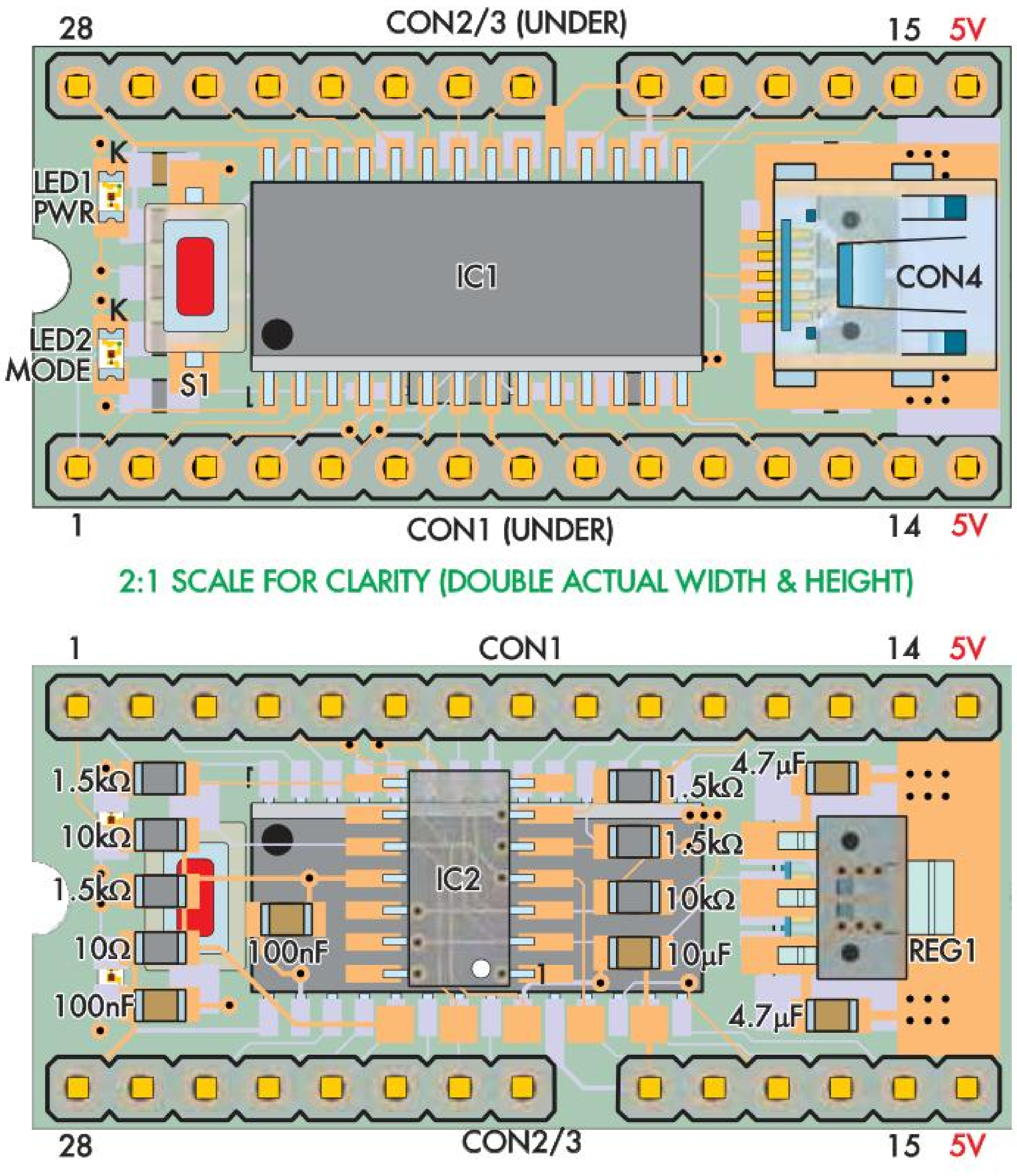
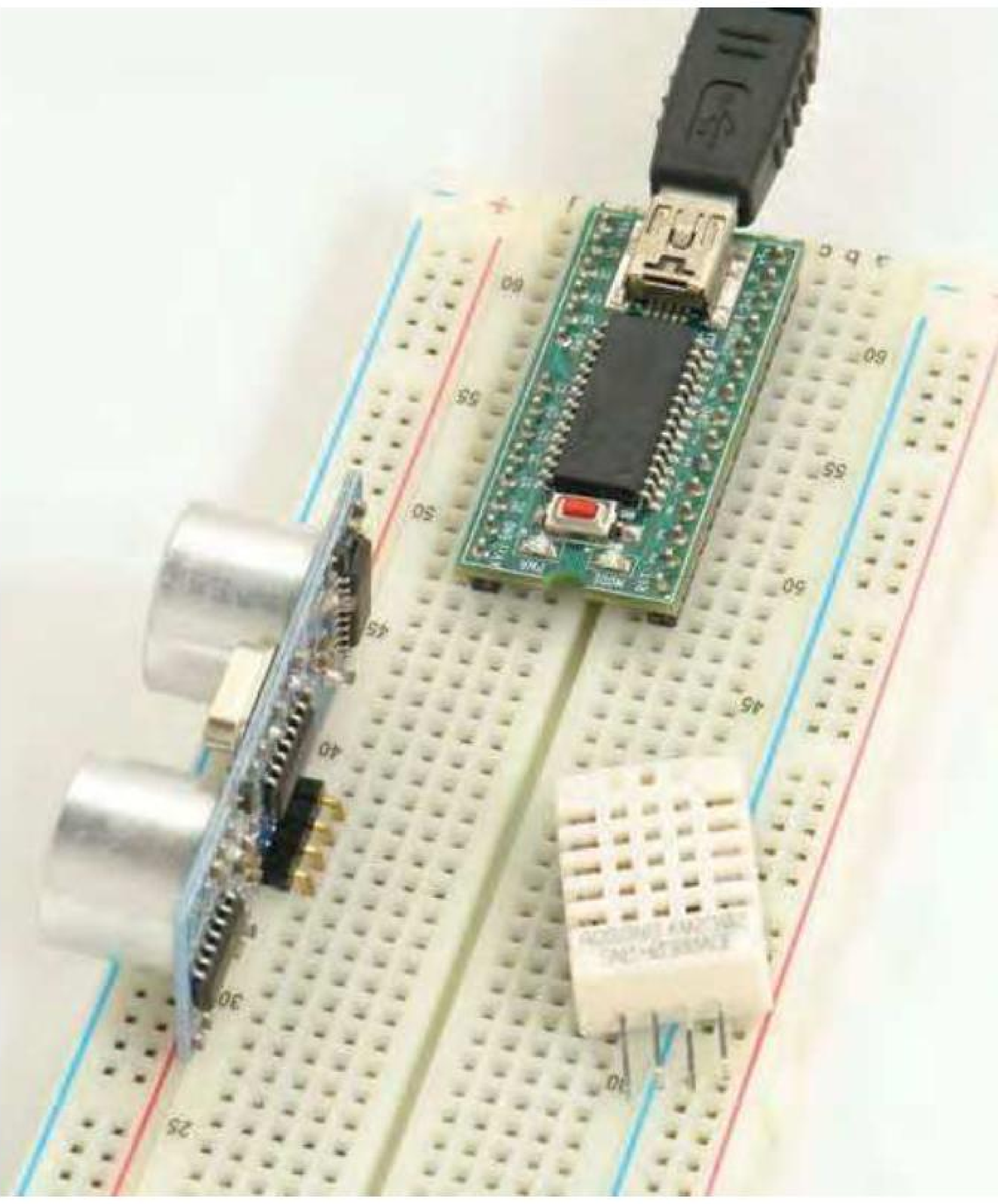


Fig.6: use these same-size photos and PCB overlay diagrams (top and bottom view) as a guide to assembling the *Explore-28*. Because the Micromite *Explore-28 is* so small, we've also prepared the twice-life-size diagrams at right to make life a little easier! As mentioned in the text, it's easiest to populate the bottom side first (with IC2 and REG1) since these components are all similar heights, so the board should still sit relatively flat while you solder the remaining components on the top side. If you're having trouble getting it to sit flat, try plugging a pair of 15-pin headers into a breadboard and then resting the PCB on top.



The *Explore-28* is designed to plug into a standard (solderless) breadboard for easy prototyping. Using the pre-assembled module, you can plug it into a USB port on your laptop, and in a few minutes have a simple program running.

If there are bridges, apply some flux paste and clean them up using solder wick. Then solder the four large mounting tabs, to hold the socket firmly to the board.

With that done, you can continue with soldering IC1; again, watch its orientation – pin 1 goes at the opposite end from the USB socket.

Then fit LED1 and LED2, with their cathodes (generally indicated with a green stripe or dot) towards the 'K' shown in Fig.6 (shown on the PCB itself as white squares). But note that while *most* LEDs have a green dot or stripe to indicate the cathode, we've seen LEDs where it indicates the anode.

So to be extra safe (and avoid a lot of fiddly rotating of components later), it's best to probe each end of the LEDs with a multimeter set on diode-test mode.

When they light up, the red probe is on the anode and the black probe on the cathode.

Finish up by soldering pushbutton S1 in place, followed by the headers, fitted to the underside of the board as shown.

Testing

To test the completed *Explore-28*, simply connect it to a USB port on your computer and program the latest firmware into the Micromite as described above (if your Micromite chip wasn't already programmed).

Then check that you can get the MMBasic command prompt via a terminal emulator. If you can, it means that everything is working perfectly.

If you do not see the virtual serial port created by the *Microbridge* on your computer, the first thing to check is that the voltage regulator is producing 3.3V (measure between pins 13 and 8).

If this is OK, then the *Microbridge* chip is probably at fault, with the most likely causes being poor soldering or an incorrectly programmed chip.

If you can connect via the USB-to-serial interface but you do not see the Micromite's prompt, you should check that the Micromite was programmed correctly, that the capacitor on pin 20 is of the correct type and, of course, that your soldering is good.

A handy check is the current drawn by the completed module. This is normally about 36mA.

You would need to connect an ammeter between a 4-16V DC supply and the bottom row of pins on the board to measure this.

If it is closer to 15mA, the Micromite chip is not running correctly, while a current draw of less than 5mA points to a problem with the voltage regulator.

So, there you have it. The *Explore-28* is an easy-to-use microcontroller module that you can use as the brains of your next project. It is a fun electronic building block to play with and an excellent way of learning to program in the BASIC programming language.

Where to buy the Explore-28…
… parts, kits and modules

- **A full kit, major parts or a complete pre-assembled module is available from the dedicated UK Micromite store at: https://micromite.org/**

- **Also visit the Rictech Ltd website for a downloadable construction pack with PCB and firmware: www.rictech.nz/micromite-products**

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Micromite Resources

Latest firmware versions, manuals and tutorials: .... **http://geoffg.net**
'Getting Started with the Micromite' and 'Micromite User Manual': .... **http://geoffg.net/micromite.html#Downloads**
The Back Shed forum, where many knowledgeable users can help newcomers:.... **www.thebackshed.com/forum/Microcontrollers**

Microbridge Resources

Firmware for the Microbridge (PIC16F1455) in the Explore-28: .... **http://geoffg.net/microbridge.html#Downloads**
pic32prog, used to program new firmware into the Micromite (Windows):............. **http://geoffg.net/microbridge.html#Downloads**
P32P, a user-friendly GUI interface for pic32prog.exe (Windows): .... **www.thebackshed.com/docregister/ViewDoc.asp?DocID=21**

Terminal Emulators

Tera Term, the standard terminal emulator used with the Micromite: **http://tera-term.en.lo4d.com/**
GFXterm, a terminal emulator designed specifically for use with the Micromite. It works with the Micromite's built-in editor and supports a set of graphics extensions: .... **www.thebackshed.com/docregister/ViewDoc.asp?DocID=22**
MMEdit, a complete IDE (Integrated Development Environment) specifically designed for the Micromite. It includes advanced features such as colour-coded text, formatting, download and run, and more: .... **www.c-com.com.au/MMedit.htm**

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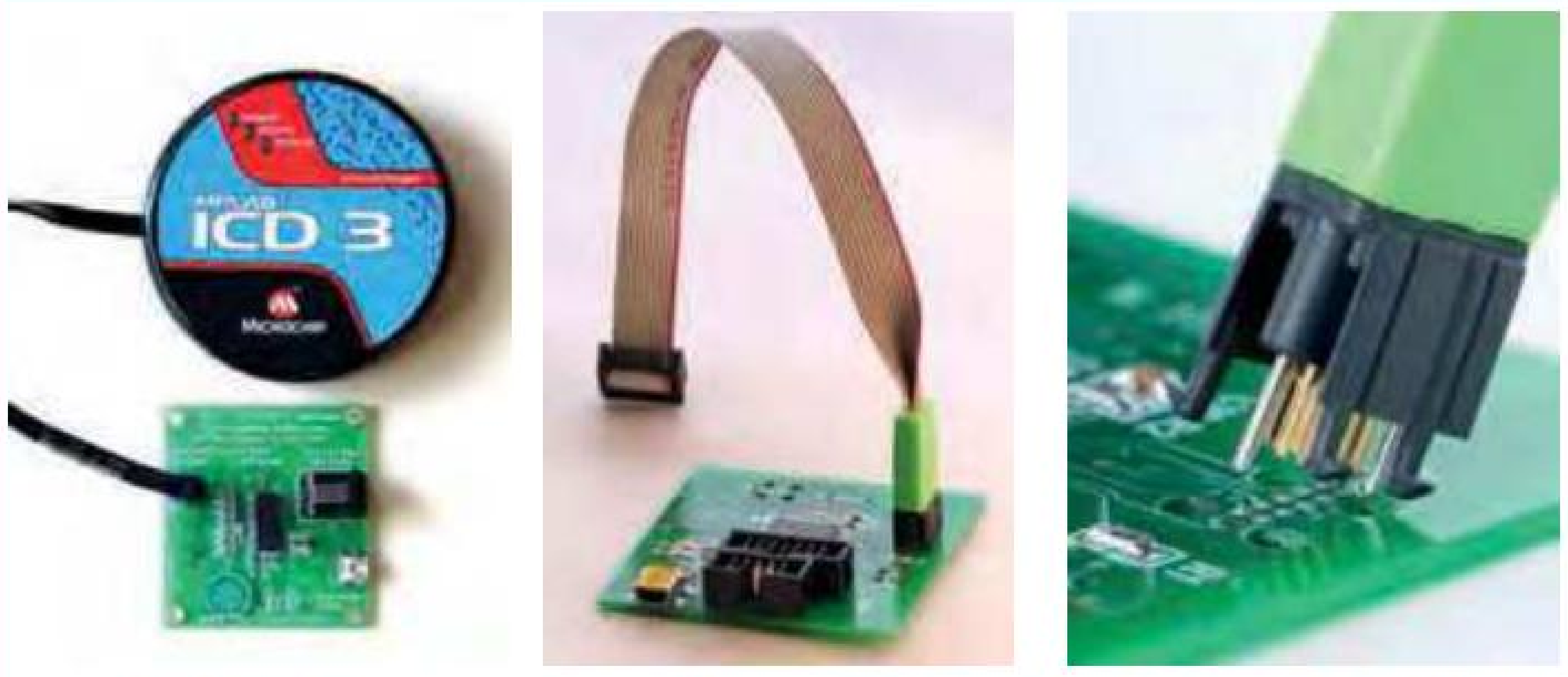

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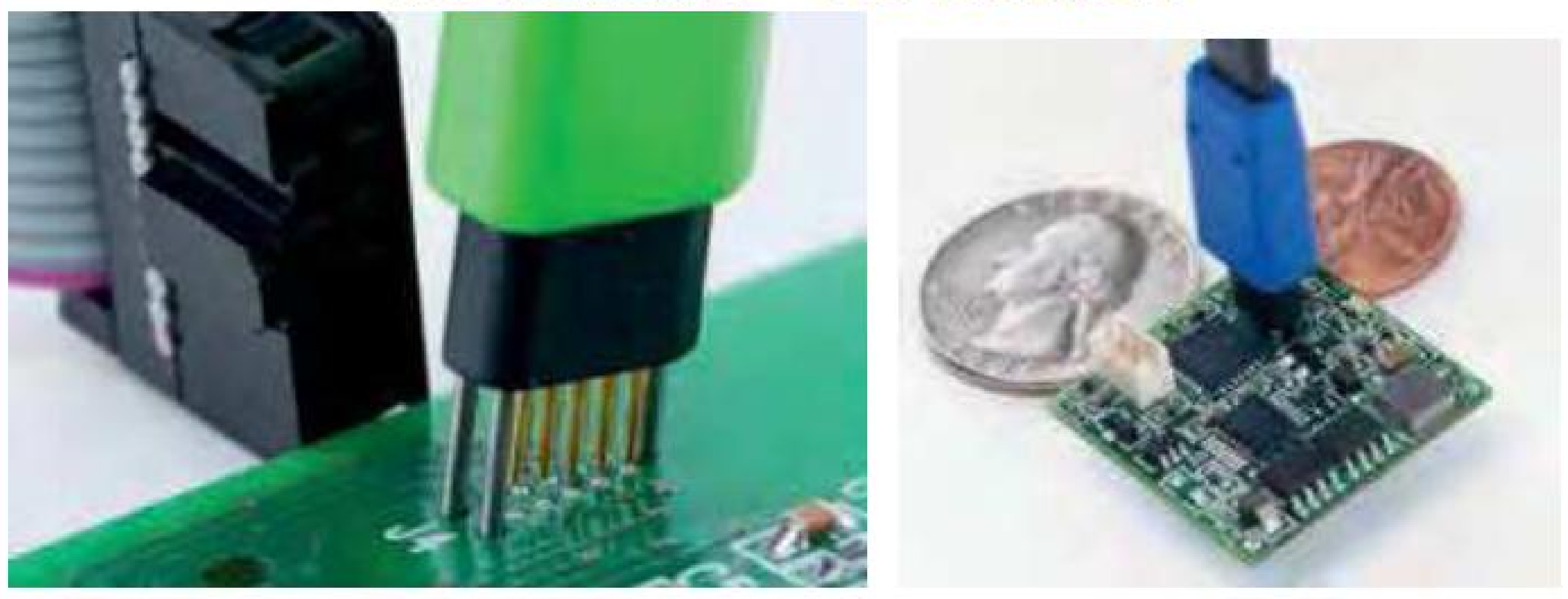

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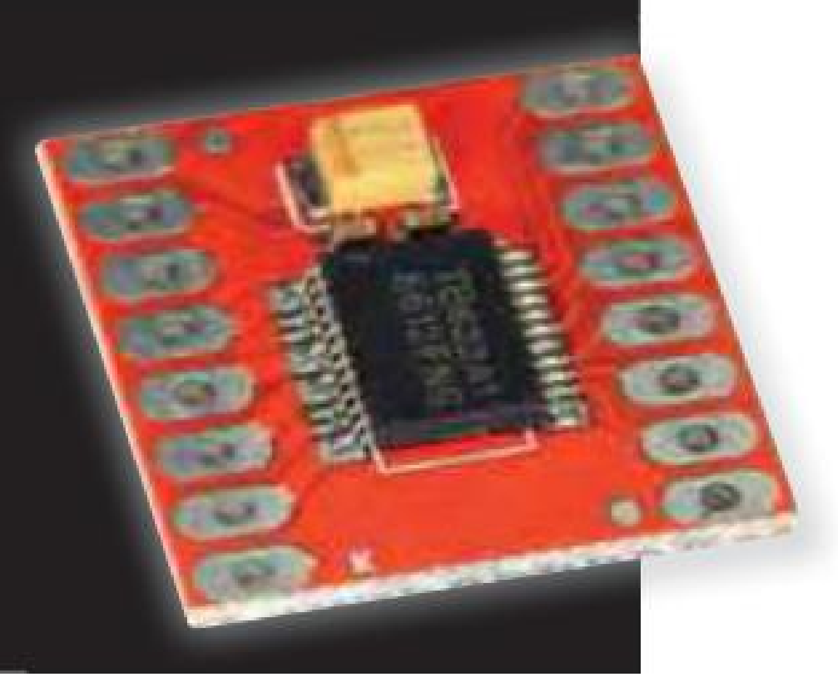
Using Cheap Asian Electronic Modules Part 24: by Jim Rowe

Three Stepper Motor Drivers

MOTORA
VMS
GND
5V
MOTORB
CSA
CSB
U1
U2
U3
U4
5V_EN
ENA
IN1
IN2
IN3
IN4
ENB
V1.4
20140214800

Want to build your own 3D printer or CNC machine? You'll need multiple stepper motors to control it, and a way to drive them. Or maybe you have some stepper motors from old printers or disc drives and want to reuse them. Here are three of the most common stepper motor driver modules and how to use them.



This article assumes you understand the basics of how stepper motors work. If you want an introduction to this type of motor then read Paul Cooper's excellent *Using Stepper Motors* series in the October 2019 to February 2020 issues.

Our first driver module is also the largest, at 60 × 55 × 28mm, including the finned heatsink for the driver IC. It's based on the ST Microelectronics L298N dual H-bridge driver chip and is currently available on eBay for around £3 to £4.50 (at the time of writing see item 182636983939). If you don't mind waiting up to a month for delivery, then AliExpress sell this item for nearly half the eBay price.

The 'N' on the end of the chip version signifies that it's in a 15-pin Multiwatt Power package, intended to be mounted vertically on a heatsink. ST Micro also make a similar version (L298HN) intended to be mounted horizontally, and a version in a PowerSO20 SMD package (L298P).

Fig.1 shows a simplified block diagram of what's inside the L298. It has two full H-bridge drivers (using bipolar power transistors) and so can drive both stator windings of a standard two-phase bipolar hybrid stepper motor.

Each bridge has an enable input and two logic control inputs, and both bridges have their negative supply connections brought out separately, to allow for an external current-sensing resistor (RSA and RSB, shown in red).

The L298 can operate from supply voltages from 6-46V and can handle up to 2A per bridge. The inputs are TTL compatible. This makes it the most rugged of the driver ICs we're looking at here, especially when it's fitted to that 23 × 25 × 15mm finned heatsink.

Fig.2 shows the full circuit of the L298N-based driver module. In addition to the L298N chip itself (IC1), there's regulator REG1, which provides a 5V supply for the logic circuitry from the stator supply voltage V_{MS}, if no separate 5V supply is available. REG1 is enabled simply by leaving the jumper shunt in place on the '5V_EN' header.

There are also eight MDDM7 fast-switching silicon diodes to ensure that all four outputs of IC1 are protected from damage due to back-EMF spikes from the motor stator windings, at the end of each current pulse.

The upper diodes prevent the outputs from swinging more positive than one diode forward-voltage drop above the supply voltage (V_{MS}), while the lower diodes prevent them from swinging below ground by more than one diode forward drop.

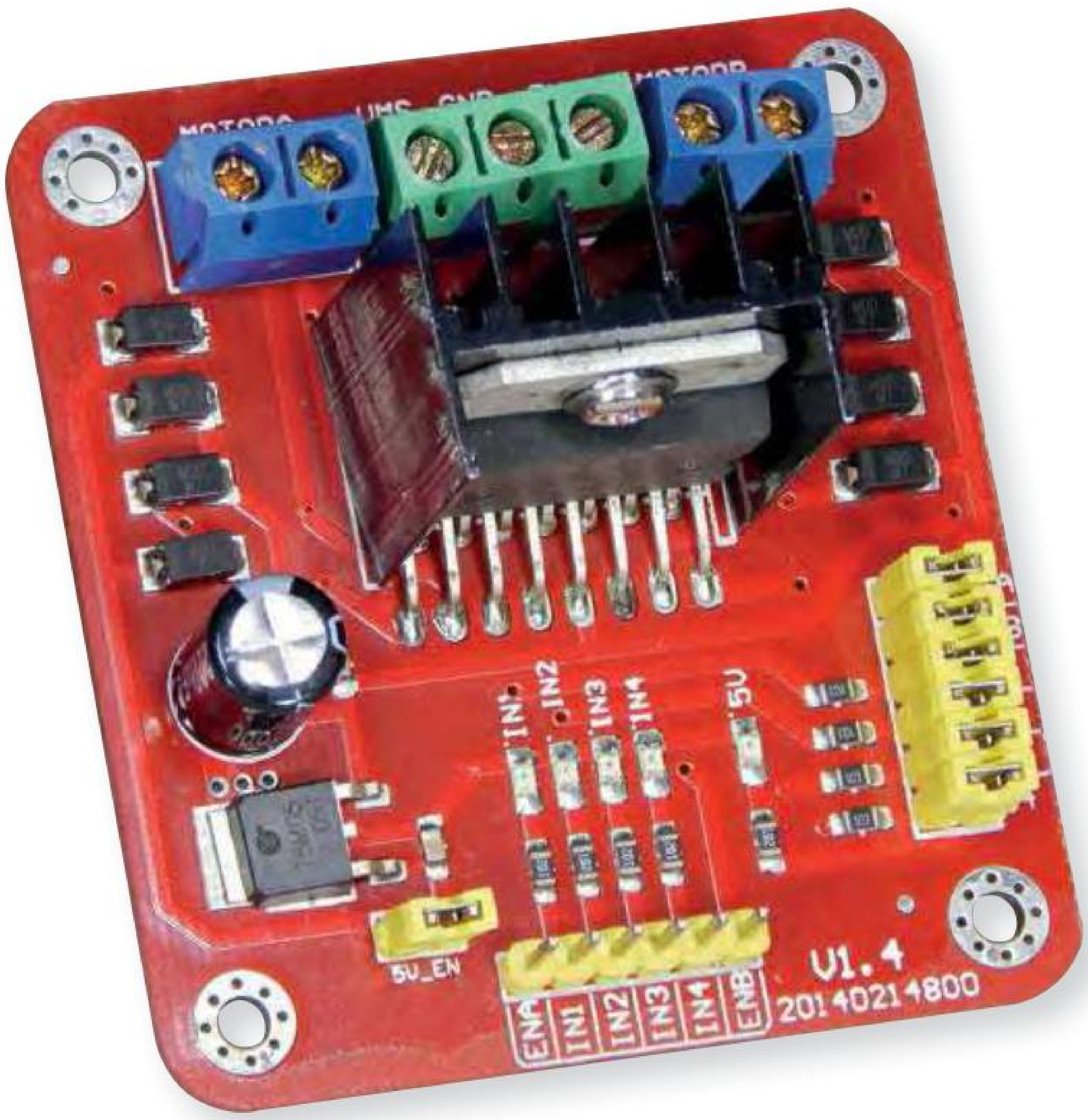
Note that there are no current-sensing resistors fitted between the Sense_A (pin 1) and Sense_B (pin 15) pins of IC1 and ground. Instead, these pins are brought out to the two pairs of header pins (CSA and CSB) at the right-hand end of the 6x2 pin DIL header, just below IC1 in Fig.2.

This allows you to connect in current-sensing resistors if you wish, or just short both pins to ground (by leaving the jumper shunts in place) if you do not need current monitoring.

The other four pairs of header pins (U1-U4) allow you to disconnect the four 10kΩ pull-up resistors between the control inputs of IC1 and +5V. Four of the five indicator LEDs (LEDs1-4) show when each of the four logic inputs is high, while the fifth (LED5) is a 5V power-on indicator.

This module is quite flexible but it does have one significant shortcoming: it is purely a dual H-bridge stepper driver, lacking any built-in indexing controller.

ST Micro make a matching controller chip for use with the L298, called the L297. This can control the L298 for full- or half-stepping, wave microstepping and clockwise or anticlockwise rotation. It can also sense the voltages across the current sensing resistors CSA and CSB, and use PWM to control and regulate the stator winding currents. However, the L297 chip costs around £10 – two to


MOTORA
VMS GND 5V
MOTORB
IN1
IN2
IN3
IN4
5V
5U_EN
V1.4
20140214800
ENA
IN1
IN2
IN3
IN4
ENB

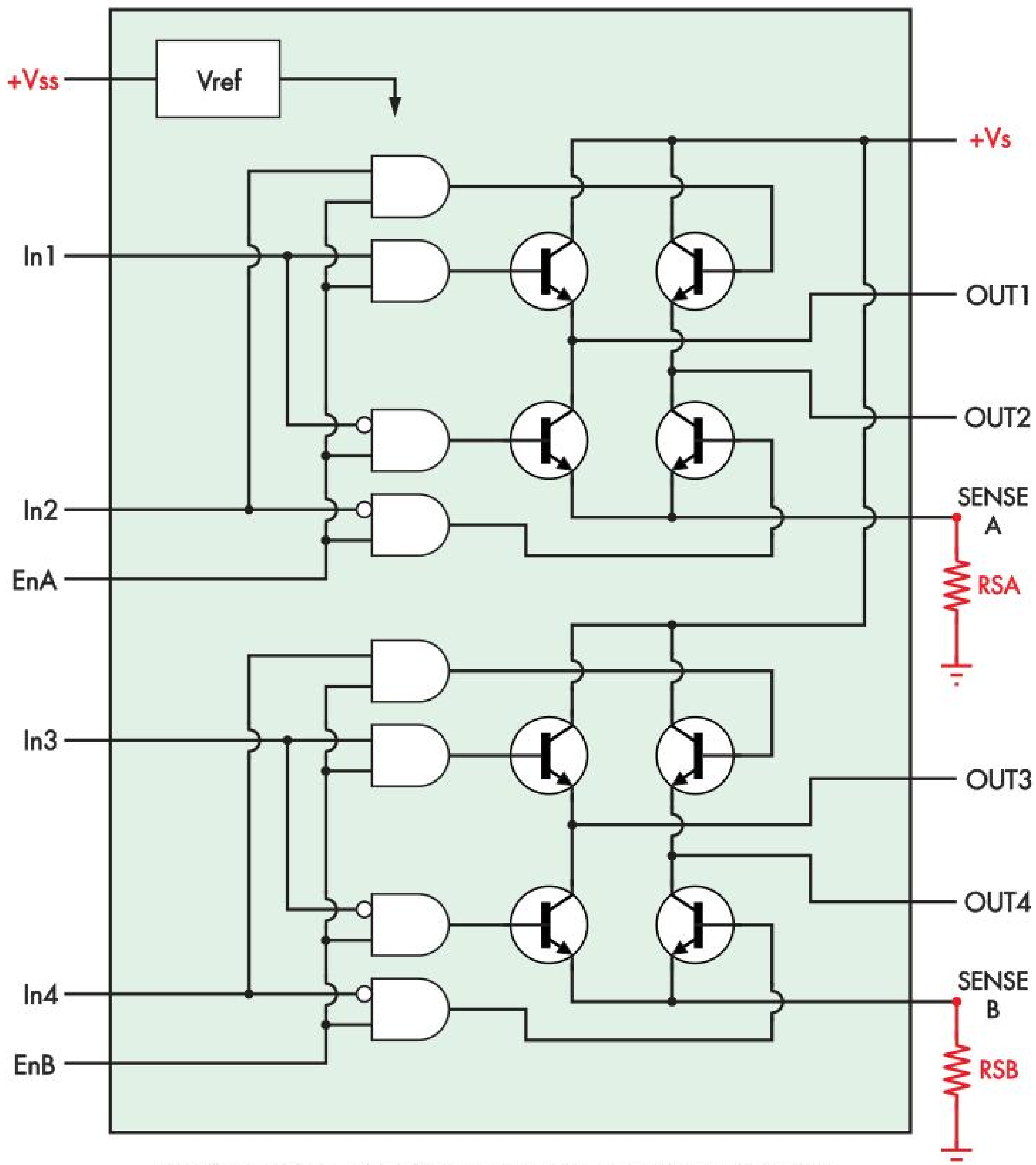

+Vss
Vref
In1
In2
EnA
In3
In4
EnB
+Vs
OUT1
OUT2
SENSE A
RSA
OUT3
OUT4
SENSE B
RSB

Fig.1 (right): block diagram of the L298N IC, which is shown as part of the module above, attached to the heatsink.

INSIDE THE L298 DUAL FULL-BRIDGE DRIVER

three times the price of the L298 module itself. Instead of using an L297 controller chip, you can use software running in your Arduino, Micromite or some other micro. Developing this can be a bit of a challenge but it is by no means impossible.

By the way, the L298N module isn't restricted to driving a stepper motor. It can also be used to drive a pair of conventional brushed DC motors – one from each of the two H-bridges.

All you need to do is feed one input of each bridge with a PWM (pulse-width modulated) pulse stream. You could drive one input for clockwise rotation and the other for anticlockwise rotation.

DRV8825-based module

The next module is much smaller and combines a stepper motor controller and driver, both within the Texas Instruments DRV8825 chip. The module measures just 20 × 15 × 16mm, including the stick-on heatsink; and is currently available from eBay suppliers for around £1.25 each (at the time of writing, see item 392867154045).

The DRV8825 chip packs a lot into a 28-pin SSOP (SMD) package, as you can see from the internal block diagram in Fig.3.

There are two full H-bridge drivers, labelled MOTOR DRIVER A and MOTOR DRIVER B. These use N-channel

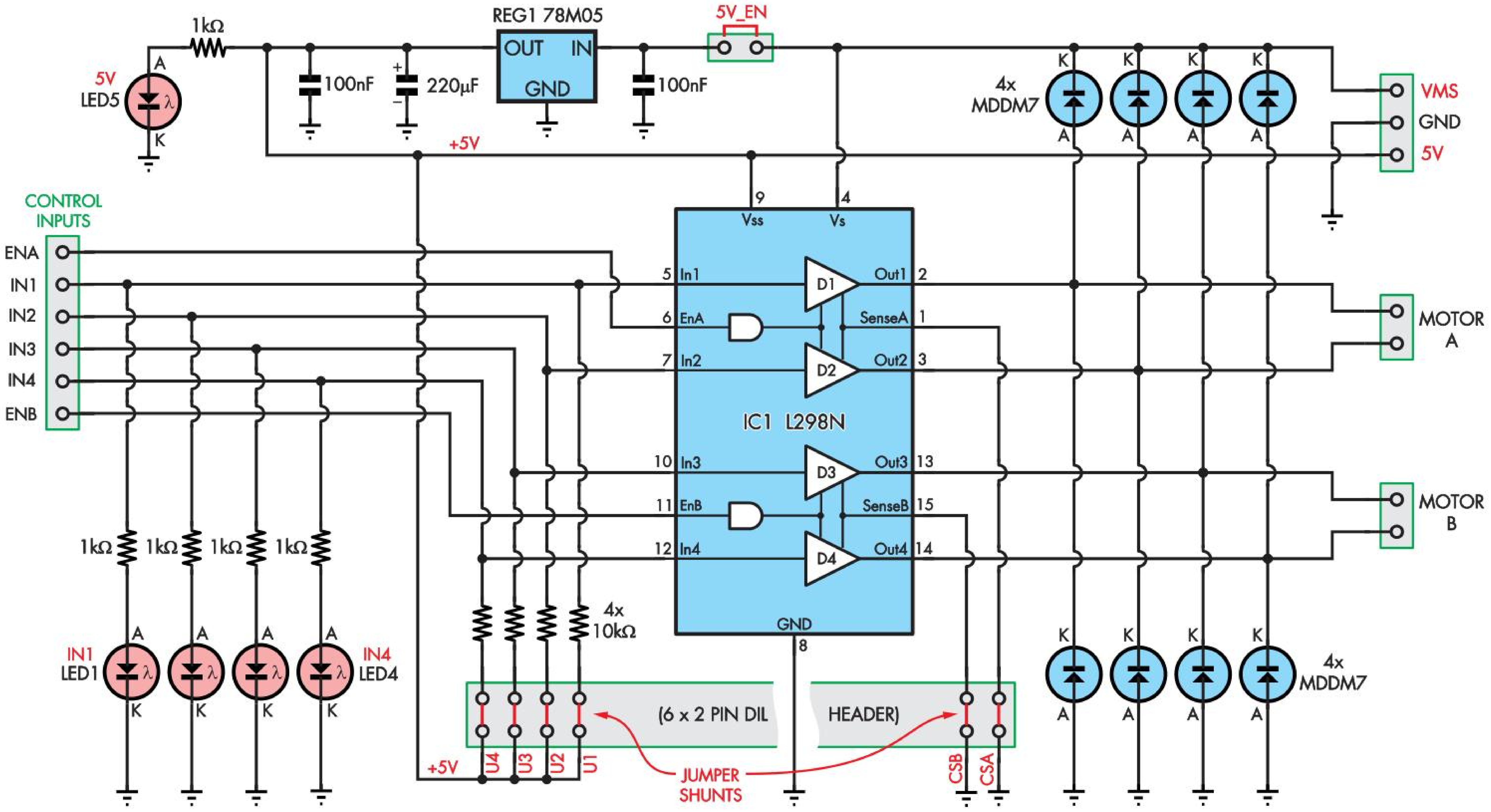

1kΩ
5V
LED5
A
K
100nF
220µF
REG1 78M05
OUT
IN
GND
100nF
5V_EN
+5V
4x
MDDM7
VMS
GND
5V
CONTROL INPUTS
ENA
IN1
IN2
IN3
IN4
ENB
9
4
Vss
Vs
5 In1
6 EnA
7 In2
10 In3
11 EnB
12 In4
D1
D2
D3
D4
Out1 2
SenseA 1
Out2 3
Out3 13
SenseB 15
Out4 14
IC1 L298N
GND
8
MOTOR A
MOTOR B
1kΩ
1kΩ
1kΩ
1kΩ
IN1
LED1
IN4
LED4
4x
10kΩ
(6 x 2 PIN DIL
HEADER)
+5V
U4
U3
U2
U1
JUMPER SHUNTS
CSB
CSA
4x
MDDM7

Fig.2: complete circuit diagram of the L298N-based stepper driver module. CSA and CSB can be fitted with two current-sensing resistors if needed, otherwise they can just be shorted to ground.

power MOSFETs and can operate with a supply of 8.2-45V, with a drive capability of up to 2.5A (for each channel) at a supply voltage of 24V.

Each driver has provision for connection of current-sensing resistors at the bottom of each bridge (I_{SENA} and I_{SENB}).

The block above the motor drivers is a charge pump used to develop the gate drive supply for the upper MOSFETs in each bridge.

Then at upper left, there's a 3.3V regulator, which can provide the current reference voltages for the two bridges (AV_{REF} and BV_{REF}).

The DRV8825 also includes its own stepper control logic/indexer block, shown at lower left. This has STEP and DIR logic inputs for basic motor control, plus three MODE control inputs (MODE0, MODE1, MODE2) which determine the stepping mode.

A total of six different stepping modes are available: Full-stepping, half-stepping, quarter-stepping and three different microstepping resolutions (8/16/32 microsteps per full step). The microstepping is performed using PWM current control, together with synthesised sine and cosine waveforms.

Internal feedback from the I_{SENA} and I_{SENB} pins allows the PWM circuitry to regulate the motor winding currents at the same time. The chip supports fast, slow or mixed current decay modes.

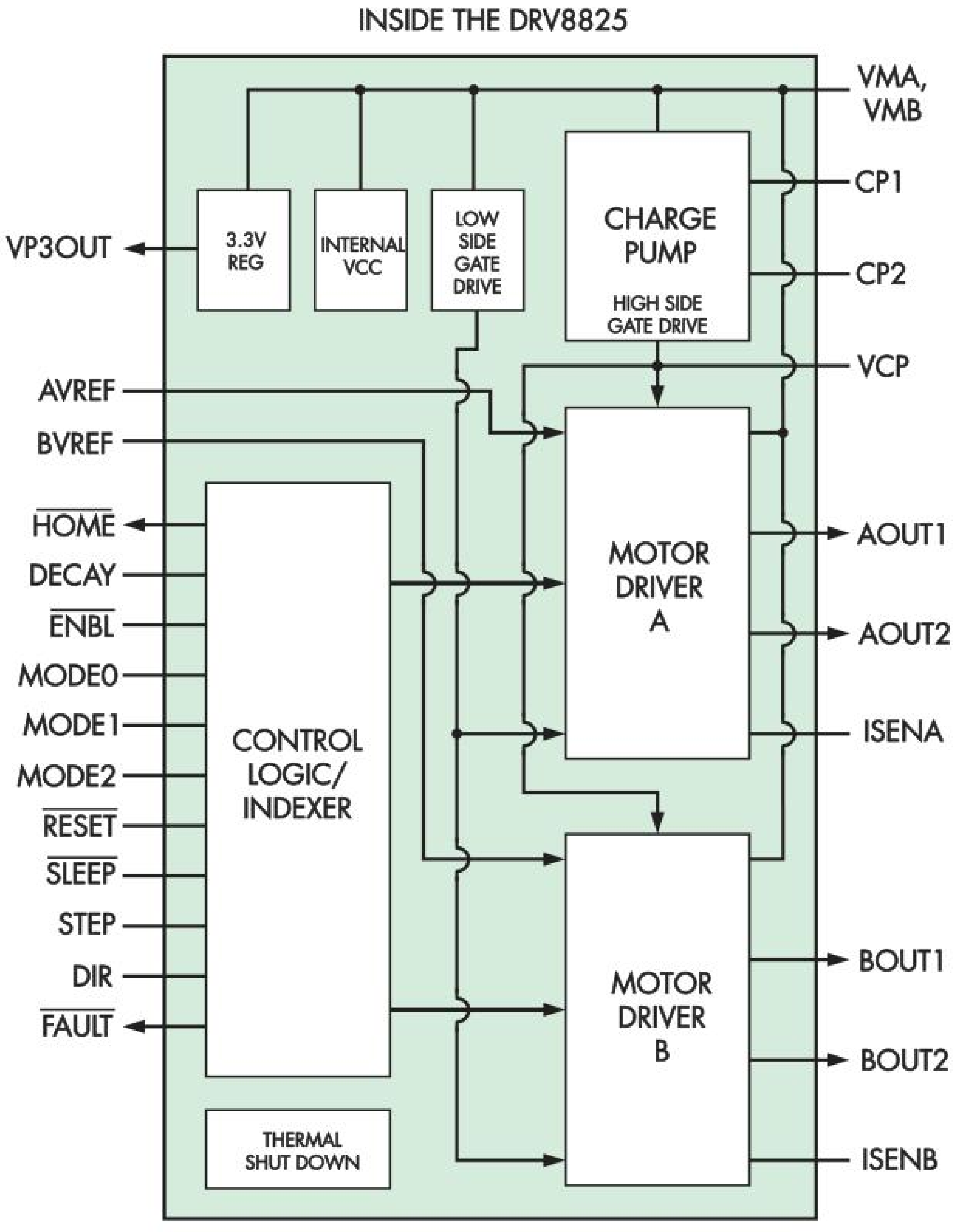

INSIDE THE DRV8825
VMA, VMB
CP1
CP2
VCP
3.3V REG
INTERNAL VCC
LOW SIDE GATE DRIVE
CHARGE PUMP
HIGH SIDE GATE DRIVE
VP3OUT
AVREF
BVREF
HOME
DECAY
ENBL
MODE0
MODE1
MODE2
RESET
SLEEP
STEP
DIR
FAULT
CONTROL LOGIC/ INDEXER
MOTOR DRIVER A
MOTOR DRIVER B
AOUT1
AOUT2
ISENA
BOUT1
BOUT2
ISENB
THERMAL SHUT DOWN

Fig.3: block diagram of the DRV8825 IC.

The $\overline{\text{SLEEP}}$ input allows the internal circuitry to be shut down for very low current drain between active motor drive periods. There are also $\overline{\text{ENBL}}$ and $\overline{\text{RESET}}$ inputs, both of which have internal pulldowns. And there's a $\overline{\text{FAULT}}$ output, which goes low if the device detects an over-temperature or over-current condition.

Fig.4 shows the full circuit of the DRV8825-based stepper driver module, and there's little in it apart from the DRV8825 chip (IC1).

The 10nF capacitor between pins CP1 (1) and CP2 (2), and the 100nF capacitor connected between the V_{CP} pin (3) and the motor voltage line V_{MA} are needed so that the internal charge pump can develop the high-side gate drive voltage for the two internal H-bridge drivers.

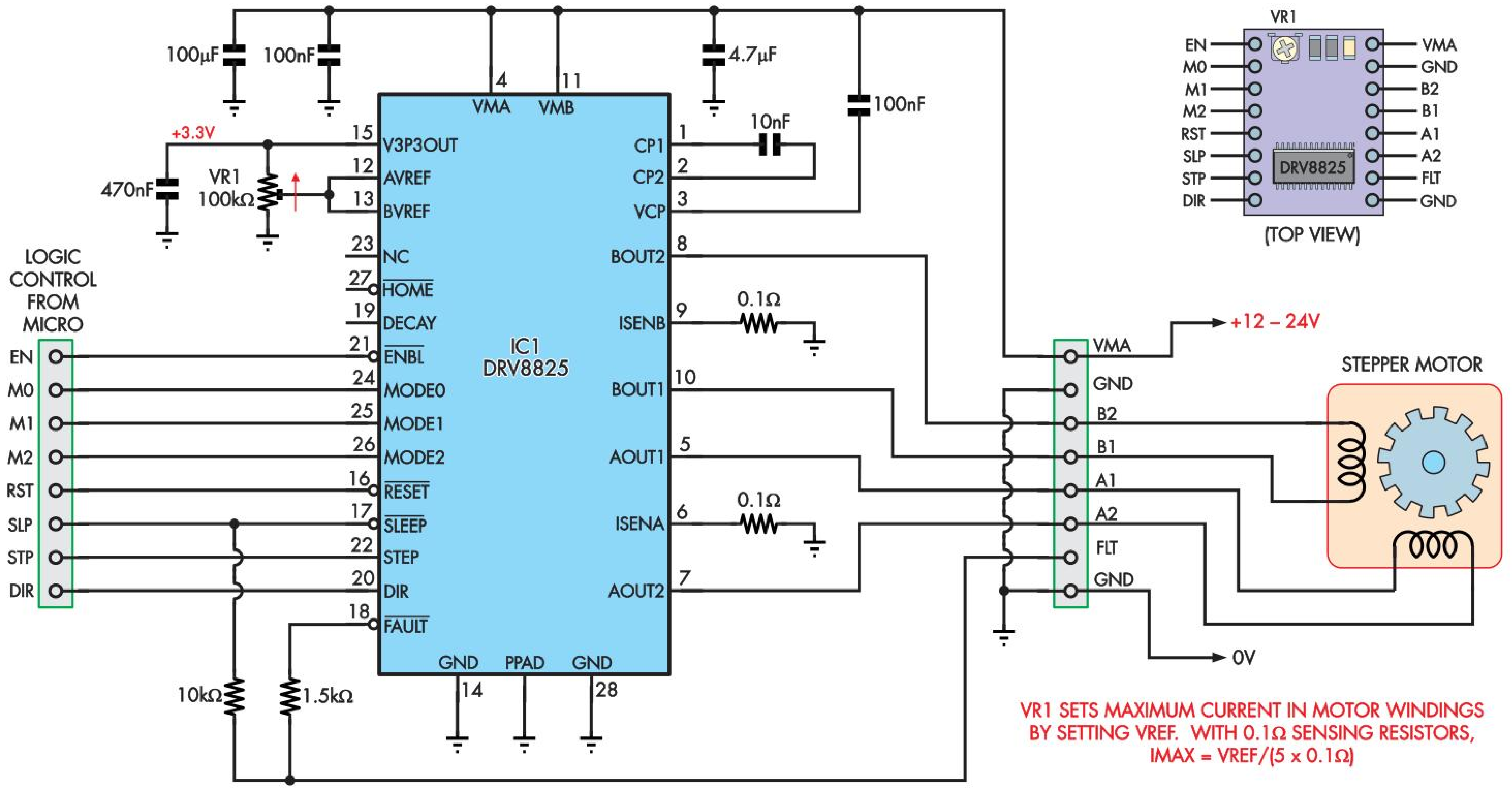
The chip's I_{SENA} and I_{SENB} output current-sensing pins are connected to ground via 0.1Ω resistors, to allow the regulation circuitry to operate. Trimpot VR1, shown at upper left, allows the maximum current level in each motor winding to be set to any desired level, by setting the voltage at the AV_{REF} and BV_{REF} pins.

The DRV8825 data sheet advises that there is an op amp with a gain of five in the feedback circuit from the I_{SENA} and I_{SENB} pins, so the relationship between the maximum motor winding current, the sensing resistor values and the V_{REF} voltage (set by VR1) is straightforward:

$$\mathbf{I_{MAX} = V_{REF} \div (5 \times R_{SENSE})}$$

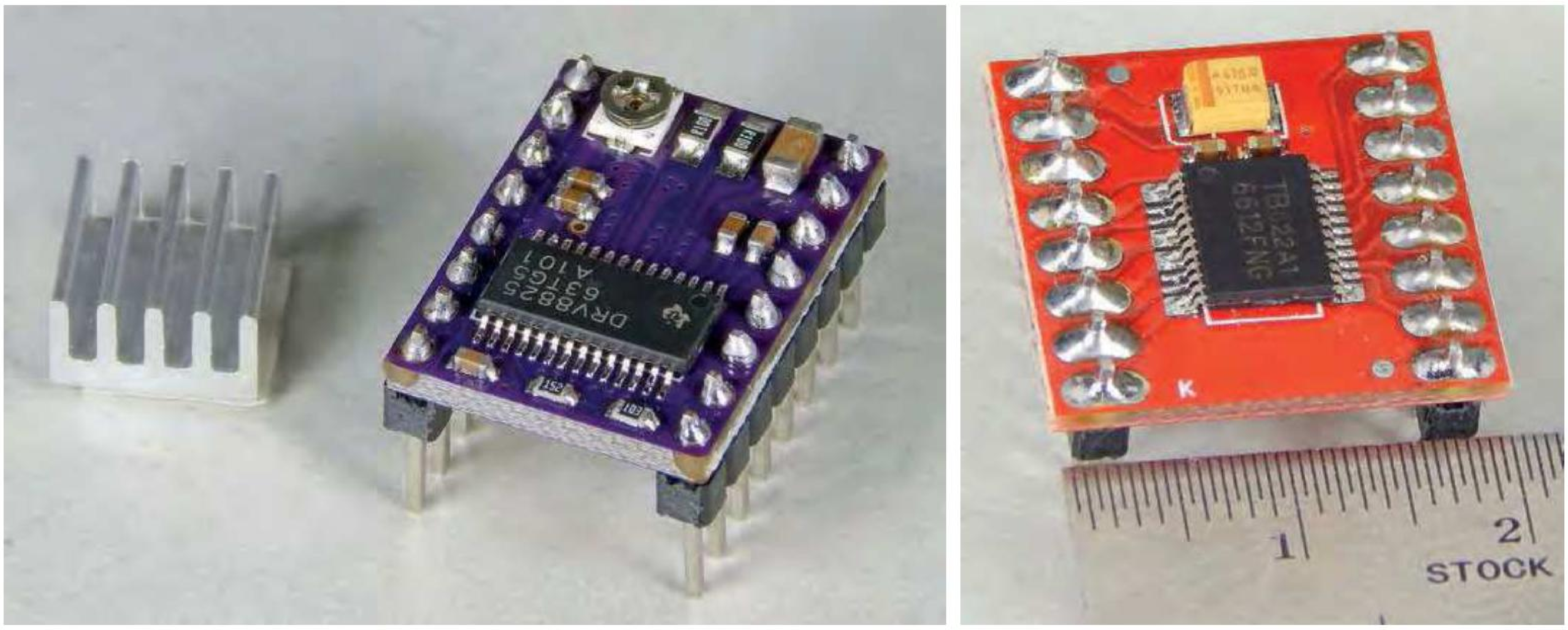
So with the 0.1Ω sensing resistors used in this module, the maximum winding current (I_{MAX}) will be equal to V_{REF} × 2. As a result, VR1 can easily set the maximum current level up to 2.5A. For example, setting VR1 so that V_{REF} = 1.0V will give a maximum winding current of 2A.

As you can see, despite its tiny size, the DRV8825 has a surprising range of capabilities, including a very flexible built-in indexing controller to


100µF
100nF
4.7µF
100nF
10nF
+3.3V
470nF
VR1 100kΩ
15 V3P3OUT
12 AVREF
13 BVREF
23 NC
27 HOME
19 DECAY
21 ENBL
24 MODE0
25 MODE1
26 MODE2
16 RESET
17 SLEEP
22 STEP
20 DIR
18 FAULT
4 VMA
11 VMB
1 CP1
2 CP2
3 VCP
8 BOUT2
9 ISENB
10 BOUT1
5 AOUT1
6 ISENA
7 AOUT2
GND 14
PPAD
GND 28
IC1 DRV8825
0.1Ω
0.1Ω
LOGIC CONTROL FROM MICRO
EN
M0
M1
M2
RST
SLP
STP
DIR
10kΩ
1.5kΩ
VMA
GND
B2
B1
A1
A2
FLT
GND
+12 – 24V
0V
STEPPER MOTOR
VR1
EN
M0
M1
M2
RST
SLP
STP
DIR
VMA
GND
B2
B1
A1
A2
FLT
GND
DRV8825
(TOP VIEW)

VR1 SETS MAXIMUM CURRENT IN MOTOR WINDINGS BY SETTING VREF. WITH 0.1Ω SENSING RESISTORS, IMAX = VREF/(5 x 0.1Ω)

Fig.4: complete circuit diagram of the DRV8825-based stepper driver/controller module. While this circuit is less complex than the L298N-based module shown in Fig.2, it doubles as a controller and driver instead of only being a driver.



The DRV8825 (left) and TB6612FNG-based module (right) shown slightly enlarged. Note the stick-on heatsink for the DRV8825, which would likely be required when driving large stepper motors with windings that pull 1A or more.

simplify controlling a stepper motor from a micro.

TB6612FNG driver module

The third stepper motor driver module is based on the Toshiba TB6612FNG chip. It's slightly larger than the DRV8825-based module, measuring only 20.5 × 20.5 × 11mm, including headers. It's available from suppliers on eBay for around £2.40 each – at the time of writing see item 254645741337.

Fig.5 shows a simplified block diagram of what's inside the TB6612FNG, which comes in a 24-pin SSOP SMD package. It's basically a pair of H-bridge drivers, each driven from a control logic block. So in many ways, it's rather like the L298N, except that the H-bridges use LDMOS power transistors rather than bipolar power transistors.

The TB6612FNG is rated to operate at a maximum motor supply voltage (VM) of 15V, and to deliver output currents of up to 1.2A average or 3.2A peak, for each channel. But it also needs a logic circuit supply voltage (V_{CC}) of between 2.7V and 5.5V, and there is no on-chip regulator to derive this from the motor supply. So this must be supplied externally.

Note that although the ground connection of each H-bridge is brought out to a pair of device pins (3 and 4, 9 and 10), these pins are all linked together inside the device.

You therefore can't individually monitor or control bridge currents. You'd have to use a single resistor, and it would develop a voltage corresponding to a vector sum of the two bridge currents.

By the way, like the L298N, the TB6612FNG does not include any indexing/control circuitry ahead of the control logic. So it too needs external indexing hardware or software to drive a stepper motor.

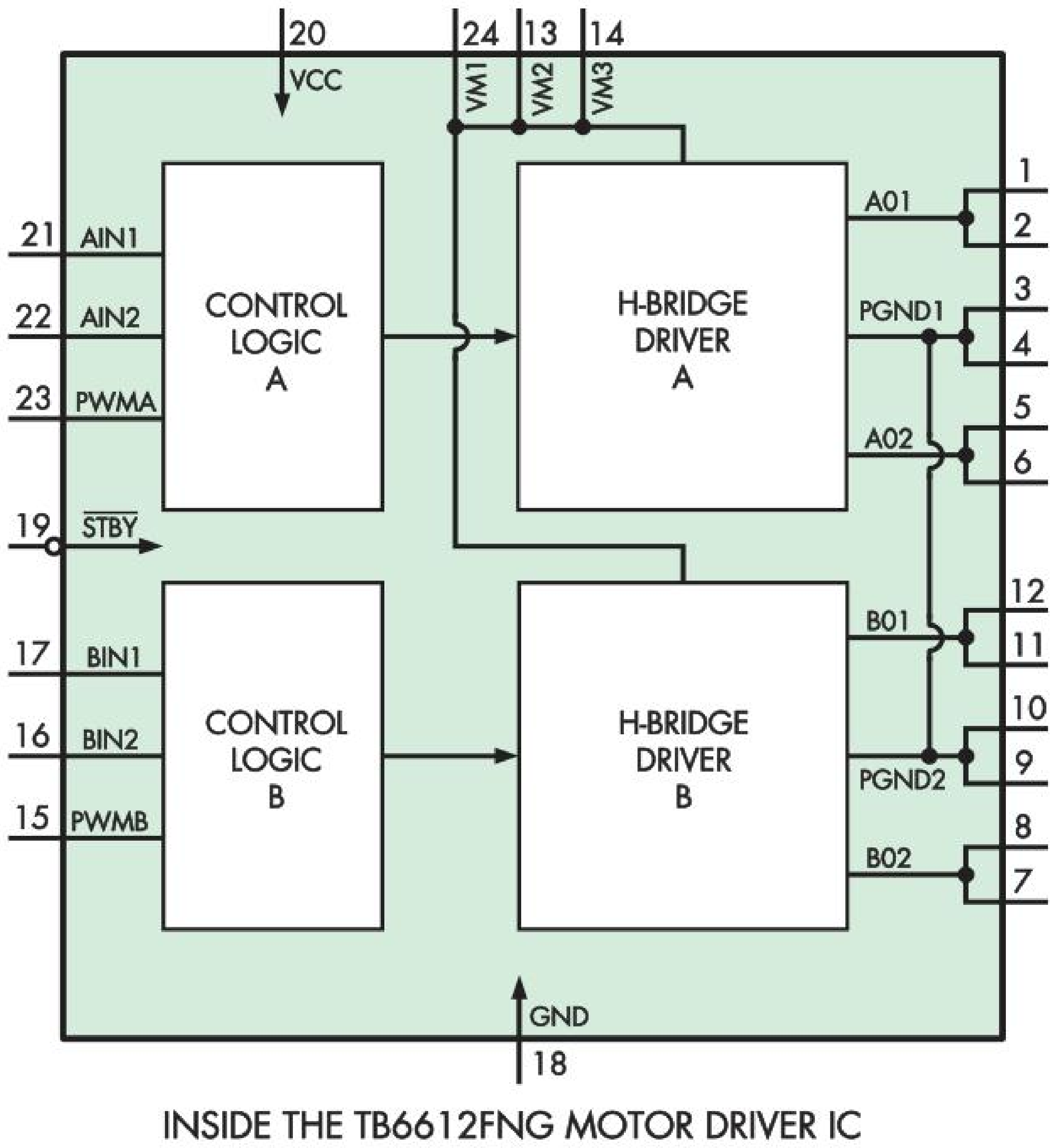
On the other hand, it's suitable for driving a pair of brush-type DC motors, using PWM input signals to control motor speed and the A_{IN1}/A_{IN2} and B_{IN1}/B_{IN2} signals to determine rotation.

Fig.6 shows the actual circuit of the TB6612FNG based driver module, and clearly, there is very little in it apart from the main chip itself (IC1).

There are just three bypass capacitors on the supply lines and two 8-pin SIL headers (CON1 and CON2) to make the input and output connections. It couldn't be much simpler.

Trying them out

Since the driving schemes of the L298N and TB6612FNG are quite similar, we've decided to concentrate on demonstrating how to use the L298N and DRV8825-based modules. And we're going to demonstrate driving


20
VCC
24
13
14
VM1
VM2
VM3
21
AIN1
22
AIN2
23
PWMA
19
STBY
17
BIN1
16
BIN2
15
PWMB
CONTROL LOGIC A
CONTROL LOGIC B
H-BRIDGE DRIVER A
H-BRIDGE DRIVER B
A01
PGND1
A02
B01
PGND2
B02
1
2
3
4
5
6
12
11
10
9
8
7
GND
18
INSIDE THE TB6612FNG MOTOR DRIVER IC

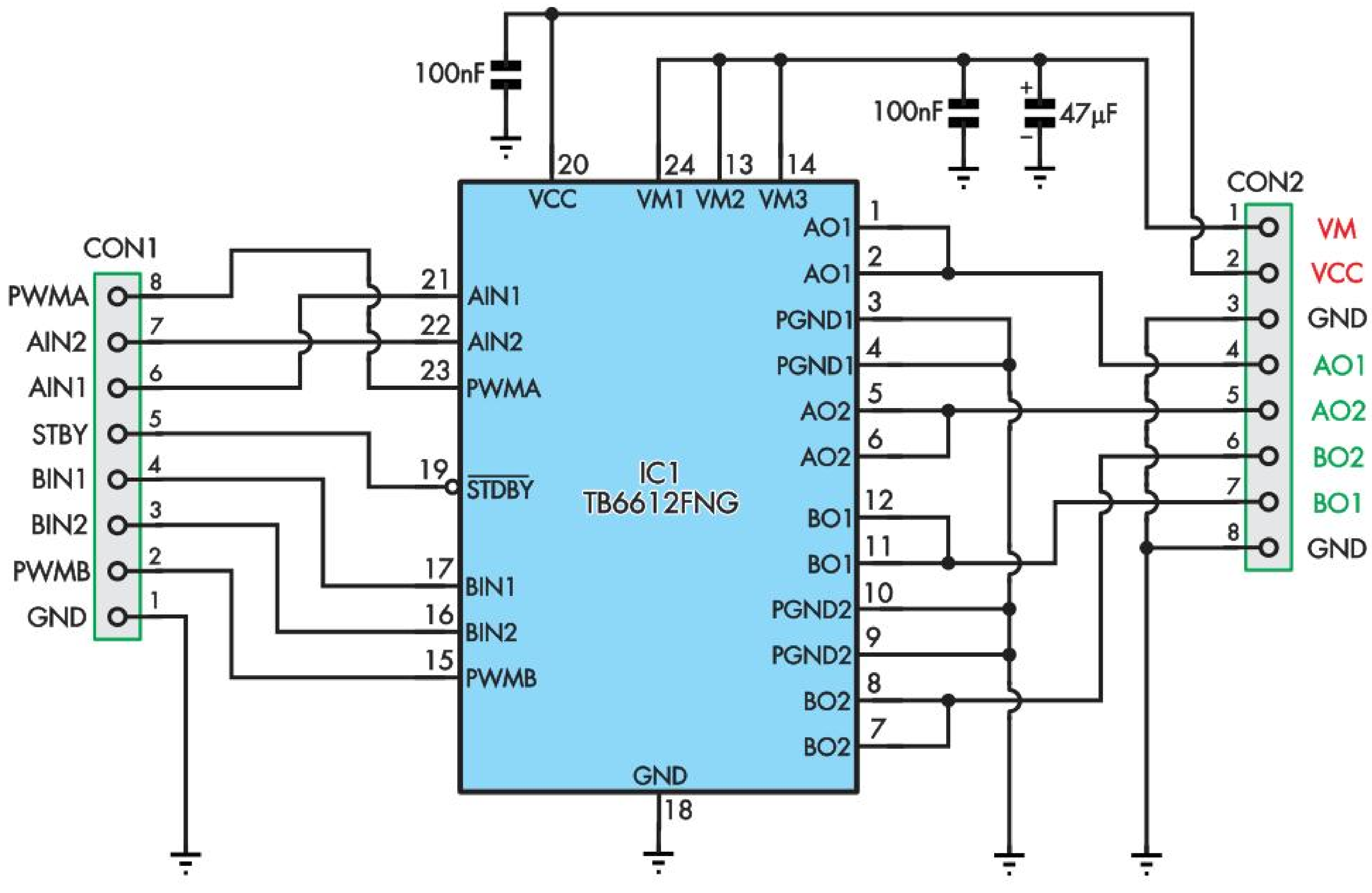

100nF
100nF
47μF
20
24
13
14
VCC
VM1 VM2 VM3
CON1
PWMA
AIN2
AIN1
STBY
BIN1
BIN2
PWMB
GND
8
7
6
5
4
3
2
1
21 AIN1
22 AIN2
23 PWMA
19 STBY
17 BIN1
16 BIN2
15 PWMB
IC1
TB6612FNG
AO1 1
AO1 2
PGND1 3
PGND1 4
AO2 5
AO2 6
BO1 12
BO1 11
PGND2 10
PGND2 9
BO2 8
BO2 7
GND
18
CON2
1 VM
2 VCC
3 GND
4 AO1
5 AO2
6 BO2
7 BO1
8 GND

Fig.5 (left): block diagram of the TB6612FNG driver IC.
Fig.6 (above): complete circuit diagram of the TB6612FNG-based module which is only a driver module and does not have any control circuitry.

Low-cost stepper motors currently available

Currently, there are quite a few new stepper motors available via eBay and other online sources.

Here's a sample of those we found in the standard NEMA sizes, together with their price range:

NEMA 11	from around £9-£30 each depending on specification
NEMA 17	£7.50 each or five for £26
NEMA 23	around £25 each

There were also many small non-NEMA steppers available at much lower prices.

For example, a 28BYJ-48 5V unipolar stepper motor bundled with a ULN2003 driver module was around £3 each or £12 for a pack of five.

one from an Arduino and one from a Micromite.

You should not have difficulty adapting our examples to different combinations of the modules and controllers if it turns out that you'd prefer to use some other pairing.

First, let's start by driving the L298N-based module from an Arduino. While this module lacks its own indexing controller, the Arduino IDE comes with a library called 'Stepper' which has functions to perform indexing. That makes hooking up controller chips like the L298N (or the TB6612FNG) quite easy.

Fig.7 shows how we connected the L298N module to an Arduino Uno and a typical bipolar stepper motor. The connections between the Uno and the module inputs are the defaults for the Stepper library, so it's important to follow these carefully.

The stepper motor windings are each connected to either the MOTOR A or MOTOR B output terminals, while the V_{MS} and GND terminals are connected to the motor power supply.

All the jumper shunts are left in place on the module.

Also, note that the module's centre GND pin needs to be connected to one of the GND pins of the Arduino. That's because there is no other connection between the two GNDs, and the control signals would otherwise not work correctly.

The Arduino IDE Stepper library comes with some example sketches written by Tom Igoe. We adapted one of these to make it easier for our readers. It's called **SCstepper_oneRevolution.ino** and you can download it from the September 2020 page of the *PE* website. It directs the stepper motor to rotate in one direction by a full revolution, then reverse and rotate back by a full revolution.

The number of steps required for a full revolution needs to be added to the sketch before you run it. The correct figure for many motors is 200, so that is the default.

If you find this sketch interesting, you'll find another three sketches in the 'Examples' folder of the Stepper library folder on your PC (if you have installed the Arduino IDE). These will all work with the setup shown in Fig.7, performing different functions.

Microstepping with the Micromite

We decided to drive the DRV8825-based module with a Micromite because its inbuilt indexer made it a little easier to program 'from scratch'.

Fig.8 shows how we connected the module between the Micromite and a bipolar stepper. The main STP and DIR inputs of the module are driven from pins 10 and 9 of the Micromite, with the $\overline{\text{SLP}}$ and $\overline{\text{RST}}$ inputs both driven from pin 16.

Similarly, the $\overline{\text{ENBL}}$ input is driven from pin 22, while the M0, M1 and M2 mode control inputs are driven from pins 21, 18 and 17 respectively.

On the output side, the motor windings are connected to the A1, A2, B1 and B2 pins, while the motor supply is connected to the V_{MA} (+12V) and GND pins. The two GND pins are also connected together, and on to a GND pin on the Micromite. This is done to ensure that both the module and the Micromite have a common ground.

An electrolytic capacitor of at least 100µF must be connected between the V_{MA} and GND pins of the module, as shown in Fig.8.

This is to provide a low impedance reservoir from which the module's H-bridges can draw current pulses – without any impedance from inductance in the power leads.

The USB-UART bridge module at top centre in Fig.8 is to program the Micromite from your PC, as well as to provide the Micromite with 5V DC.

Note that while the DRV8825 module comes with a tiny (9 × 9 × 5mm) finned heatsink which can be attached to the top of the DRV8825 chip using an adhesive patch, it is unnecessary when driving a small stepper motor from a 12V supply. Presumably, it would be required if the module is driving a reasonably large stepper motor with windings drawing over 1A from a 24V supply.

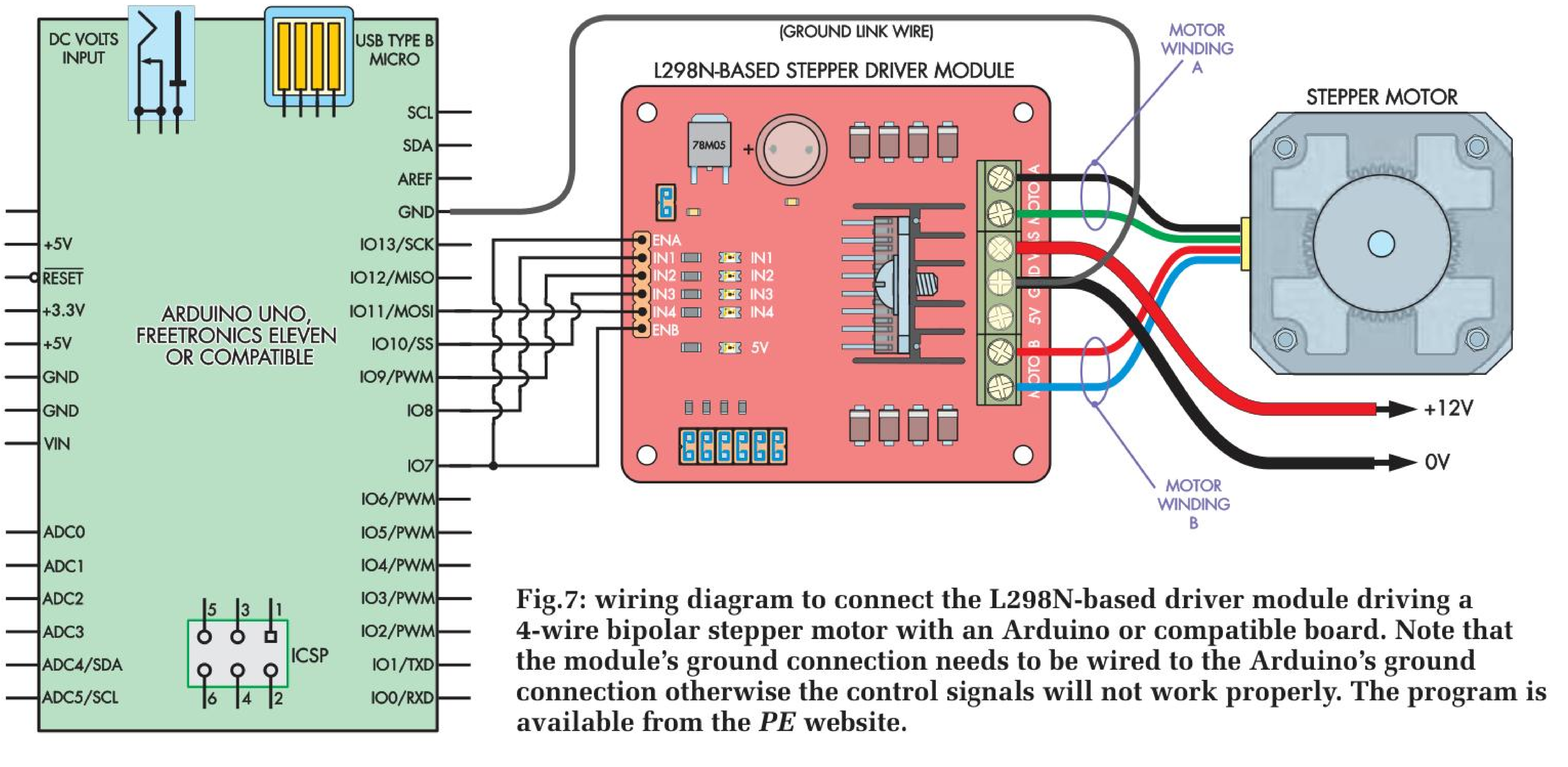
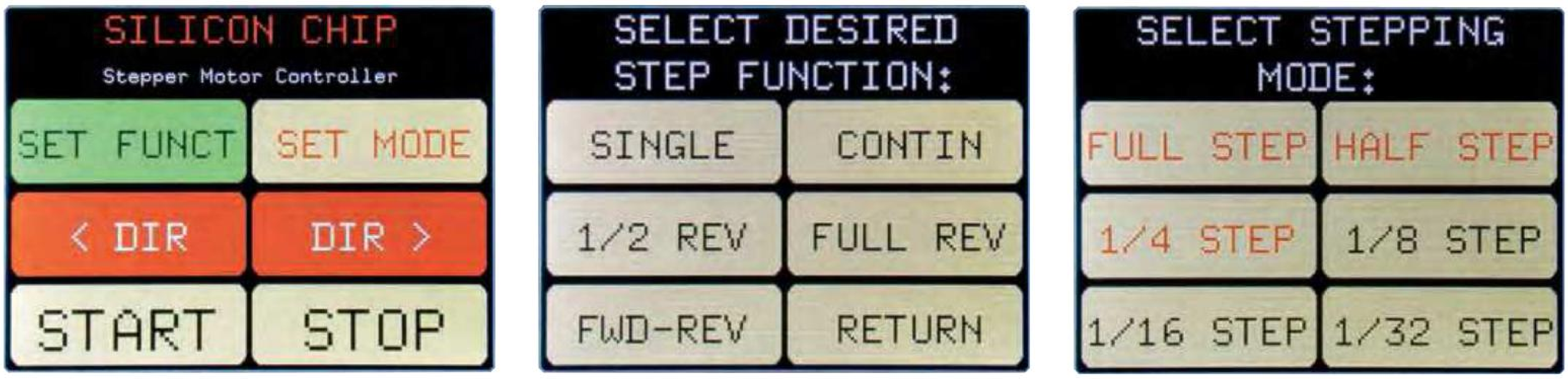


Fig.7: wiring diagram to connect the L298N-based driver module driving a 4-wire bipolar stepper motor with an Arduino or compatible board. Note that the module's ground connection needs to be wired to the Arduino's ground connection otherwise the control signals will not work properly. The program is available from the *PE* website.


SILICON CHIP
Stepper Motor Controller
SET FUNCT
SET MODE
< DIR
DIR >
START
STOP
SELECT DESIRED STEP FUNCTION:
SINGLE
CONTIN
1/2 REV
FULL REV
FWD-REV
RETURN
SELECT STEPPING MODE:
FULL STEP
HALF STEP
1/4 STEP
1/8 STEP
1/16 STEP
1/32 STEP

The three screengrabs of the example microstepping program for the DRV8825 running on a Micromite. From left to right there is the main menu at power-up, the SET FUNCT sub menu (which determine how the drive pulses should be sent) and then the SET MODE sub menu (which is used to select the stepping mode).

In our test, the winding current was only about 330mA and even without the extra heatsink, the DRV8825 became only barely warm. The module PCB provides copper patches on both sides under the chip, linked by an array of vias. So it already has a useful amount of heatsinking.

After studying TI's datasheet and application notes, I was able to write a Micromite program to control a stepper via the DRV8825 module.

This program is named **DRV8825 stepper driving program.bas** and you can download it from the September 2020 page of the *PE* website.

When loaded onto a Micromite with *LCD BackPack*, at power-up it will present you with the main screen with six touch buttons, shown in Screen 1. The buttons are labelled SET FUNCT, SET MODE, < DIR, DIR >, START and STOP. Pressing SET FUNCT loads the SELECT FUNCTION screen shown in Screen 2. This lets you choose from one of five functions:

SINGLE	Send a single step pulse each time
CONTIN	Send a large number of step pulses)
1/2 REV	Send pulses for a half revolution of the motor)
FULL REV	Send pulses for a full revolution)
FWD-REV	Send pulses for one full revolution in one direction, followed by pulses to make the motor return in the opposite direction to its original position).

The sixth button on this screen is labelled RETURN, allowing you to get back to the main screen without changing the existing selection.

If you press the SET MODE button on the main screen, you'll be presented with the SELECT STEPPING MODE screen shown in Screen 3. This allows you to select one of the six stepping modes provided by the DRV8825: FULL STEP, HALF STEP, 1/4 STEP, 1/8 STEP, 1/16 STEP or 1/32 STEP.

Touching any one of these buttons selects the desired mode and switches you back to the main screen.

The two red buttons on the main screen are used to select the direction of motor rotation. And touching the START button at lower left should result in the motor performing the selected function, using steps of the mode you've selected. The STOP button allows you to stop the motor at any time.

This program demonstrates a fair number of possibilities when it comes to using the Micromite to control a stepper motor using the DRV8825 module.

Some useful links on each of the modules are listed below:

www.st.com/en/motor-drivers/l298
www.ti.com/product/DRV8825
siliconchip.com.au/link/aama

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www.siliconchip.com.au

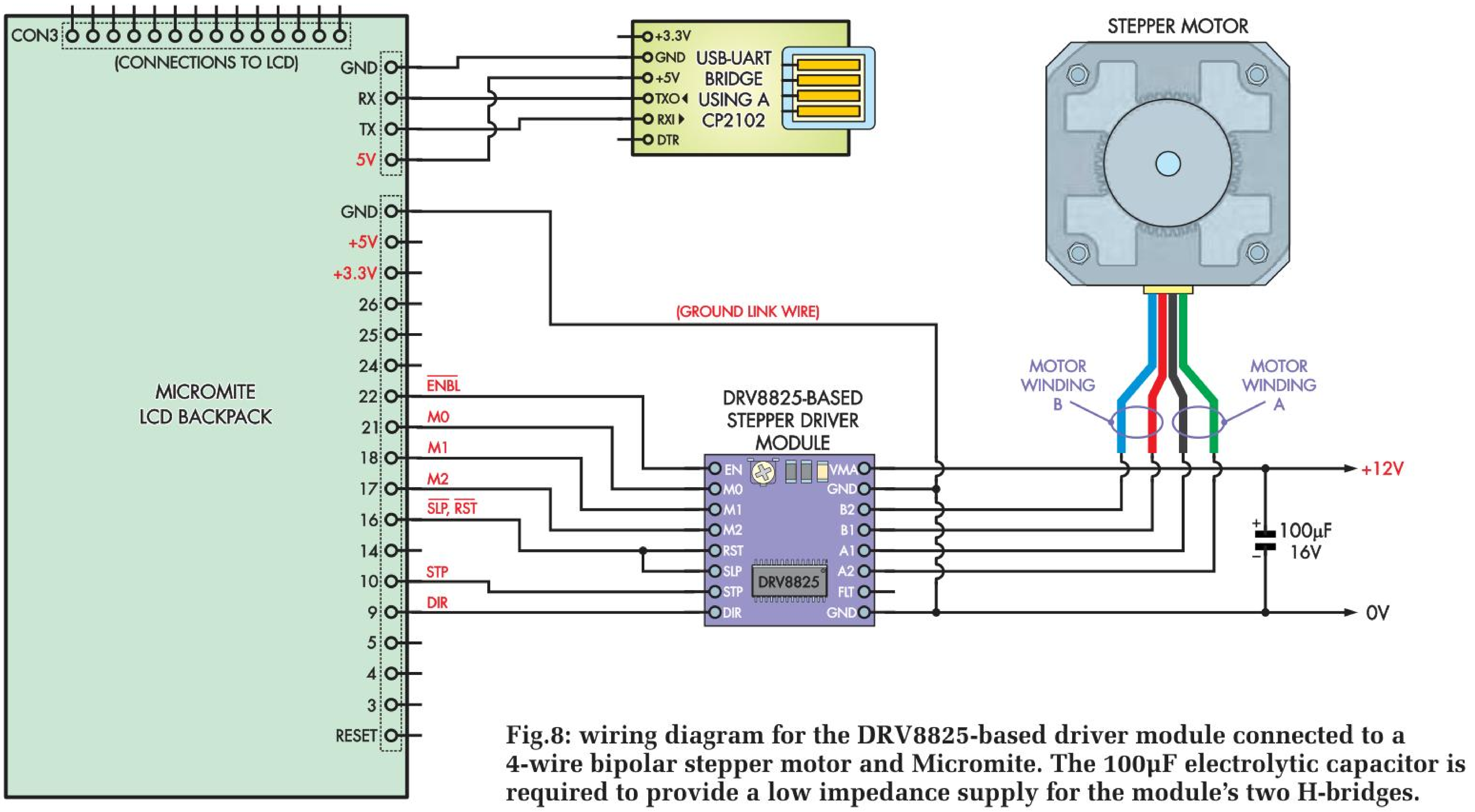
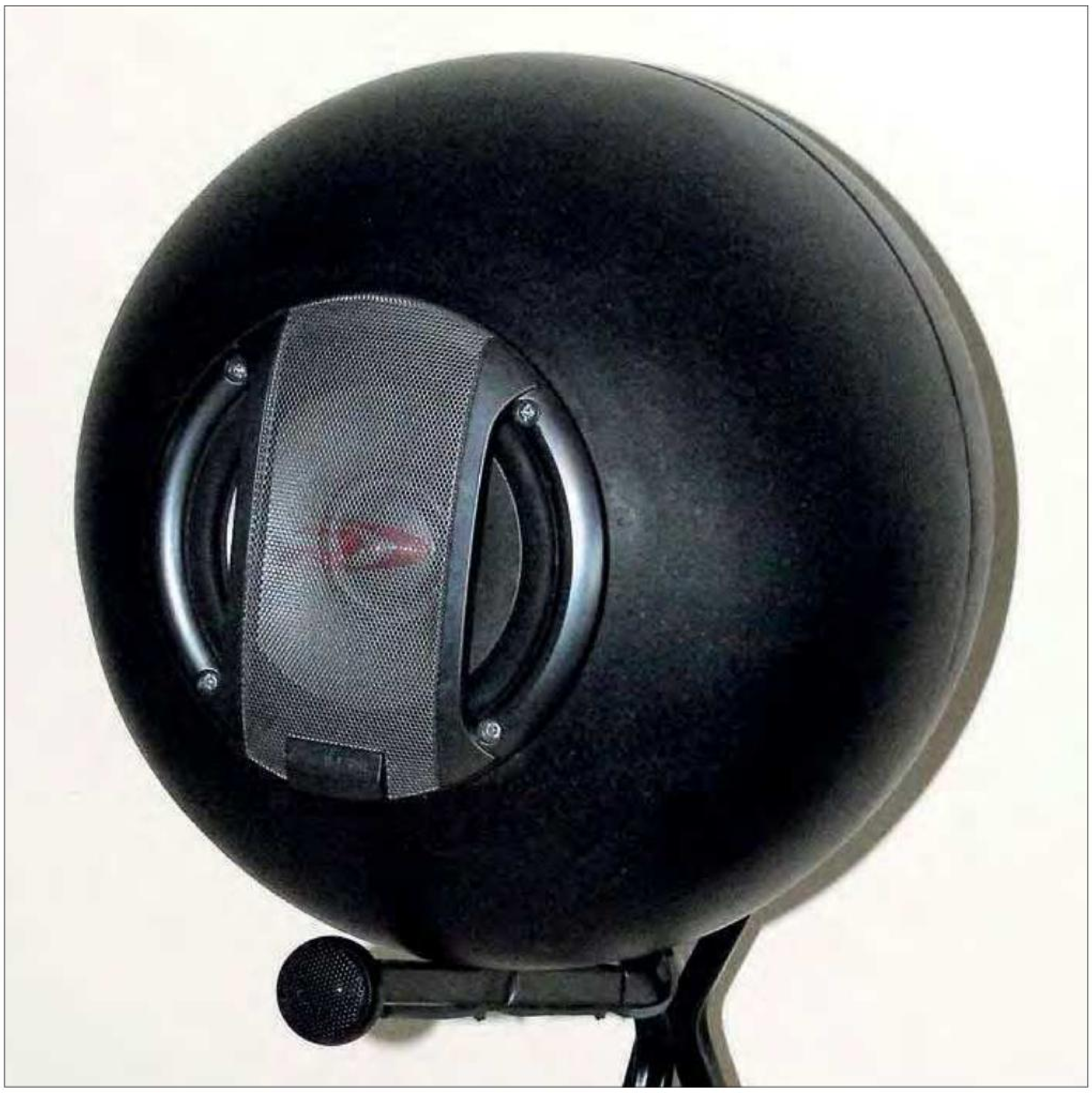

CON3
(CONNECTIONS TO LCD)
MICROMITE
LCD BACKPACK
GND
RX
TX
5V
GND
+5V
+3.3V
26
25
24
22
21
18
17
16
14
10
9
5
4
3
RESET
ENBL
M0
M1
M2
SLP, RST
STP
DIR
+3.3V
GND
+5V
TXO
RXI
DTR
USB-UART BRIDGE USING A CP2102
(GROUND LINK WIRE)
DRV8825-BASED STEPPER DRIVER MODULE
EN
M0
M1
M2
RST
SLP
STP
DIR
VMA
GND
B2
B1
A1
A2
FLT
GND
DRV8825
STEPPER MOTOR
MOTOR WINDING B
MOTOR WINDING A
+12V
100µF 16V
0V

Fig.8: wiring diagram for the DRV8825-based driver module connected to a 4-wire bipolar stepper motor and Micromite. The 100µF electrolytic capacitor is required to provide a low impedance supply for the module's two H-bridges.

Cheap and easy compact speaker enclosures

by Julian Edgar

Want to build speaker enclosures but put off by the woodwork involved? Julian Edgar describes a novel technique using clay-fibre flowerpots. They look stunning – and sound excellent, too.



Speaker building is great fun, but one of the greatest challenges in home Hi-Fi speaker construction is making the enclosures. Typically, speaker enclosures are constructed from veneered or plastic-coated particle board, and to develop good-looking and stiff enclosures usually requires access to some pretty serious woodworking machinery. A different approach is to base the enclosure design around flat-pack furniture – but when taking that route, the expense quickly adds up.

However, the enclosure design covered here takes a completely different approach – you could say, a radically different approach! Rather than make a rectangular enclosure from composite board, this approach uses clay-fibre flowerpots (planters) that are glued together. Constructing the compact enclosures takes hours rather than days, and the cost can also be quite low. Fascinatingly, this method of enclosure design also has major benefits to the sound that's developed.

First, let's go back to the beginning – how did such an unusual approach come about?

Beginnings

Near where I live, there is a small-scale manufacturer of very expensive, esoteric speaker enclosures. The enclosures are spherical and are handmade from concrete. The outer surfaces are polished or painted, and the enclosures sit on avant-garde sheet metal stands.

I wandered in one day to experience the sound. On the one hand I was impressed – the music sounded incredibly open and spacious – and on the other, underwhelmed. What I was most underwhelmed by was the price. The cost of the speakers was way out of my budget, and so I started thinking about building my own.

The constructor of the concrete enclosures uses custom moulds in which the concrete is cast. On my visit, he told me of the years of development that had gone into the technique, and how he'd had plenty of failures along the way. For a one-off pair of enclosures, the time and effort in my making moulds would be horrendous, so I wondered – was there another way of achieving a similar outcome?

That's when I discovered the joys of flowerpots!

The enclosures

The enclosures shown here use ordinary flowerpots, also called 'planters', but crucially they are made from clay-fibre (also often listed as 'fibre-clay, 'fibreclay' or similar). This material uses a mixture of traditional clay and fibre – the latter is apparently a waste product from pulp mills. Acoustically, it is relatively dead (the pots don't ring when tapped) and can be worked and cut with normal tools – more on this in a moment.

Pot shape – not just spheres

The pots I use are hemi-spherical – that is, when two are glued together, they form a sphere. However, depending on the shape of the pots that you start with, you can have all sorts of shapes. For example, if you glue together two pots having extended sides, you will end up with more of a prolate spheroid. (Yes, I had to look that one up – it means an elongated sphere.)

The curved walls of the enclosures provide excellent stiffness, reduce internal standing-wave reflection, and potentially have some advantages in reducing diffraction effects (there are no front enclosure edges).

Although the precise shape is not critical, do use circular ones, not the box-shaped ones, which are weaker, heavier and lack the acoustical advantages of pots with continuous rotational symmetry.

While I haven't done so, it may also be possible to glue a flat piece of particle board within the mouth of an elongated pot and mount the speaker driver on that. (This would still massively reduce the amount of work needed to be done over building a conventional enclosure.)

Flowerpot selection

When selecting appropriate pots, you first need to consider the internal volume required for your design. For example, does your final enclosure design need to have a volume of 15 litres – or 30 litres? Using off-the-shelf flowerpots, you obviously won't be able to have an infinite variety of internal volumes available, but if the sound is to be good, you'll need an internal volume that is close to the required design spec.

Second, ensure that the flat surface (the one on which the pot normally sits) is large enough in diameter to take the main bass driver (the woofer). In a two-way system, I mount the tweeter externally, but if you want the tweeter to be in the same panel as the woofer, the flat part of the pot will need to be larger. In ported designs, I use the rear flat area of the enclosure for the port.

Finally, the quality of clay-fibre flowerpots varies considerably, so ensure that you have solid examples. (And where to source the pots? Just wander along to your nearest large garden supplies store. Looking online, Homebase has a wide variety of clay-fibre pots.)

In addition to the clay-fibre pots, you will also need:

- Water clean-up industrial adhesive
- Polyester fibre internal damping material (I use low-cost quilt wadding)
- Acoustic components (drivers, crossovers, terminal blocks, ports)
- Basic tools, including an electric drill and an electric jigsaw. An angle grinder is useful and hastens the work, but you could use a hand file instead.

How to construct your enclosures

The accompanying photo panels and captions give you the main construction details. There is room for considerable innovation and personalisation, so stick to the basic techniques, but don't be afraid to add your own design flourishes.

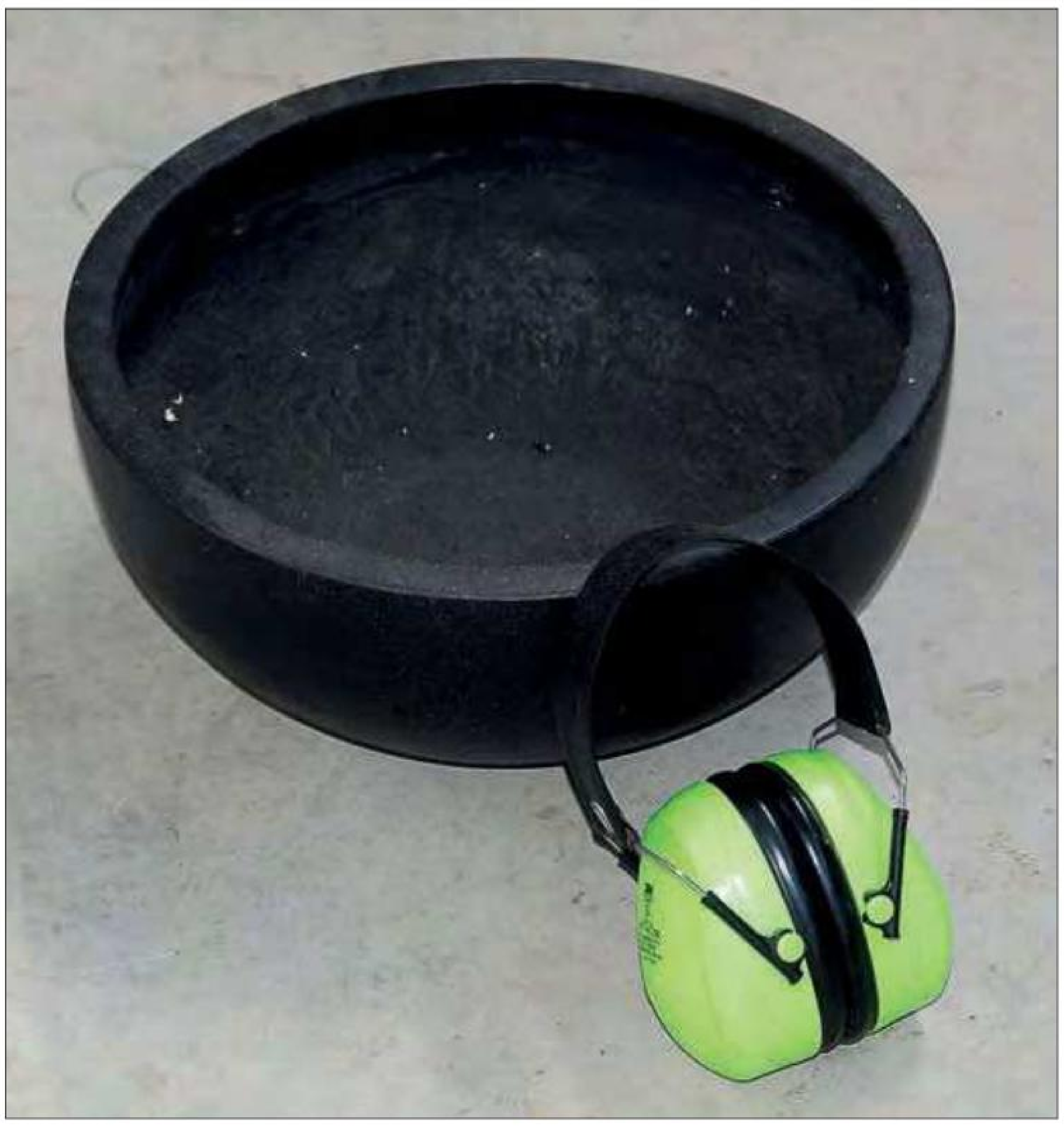


Fig.1. (above) The first step is to buy a pair of the bowls. At the time of writing, these bowls were available in 28cm, 34cm, 40cm and 51cm diameters, and in black or white finishes. The one used here is 34cm (external) diameter with a black finish. Two glued together give a 16-litre internal volume. (The ear defenders give a sense of scale and are a reminder to wear PPE when using power tools or working on a dust-generating job!)

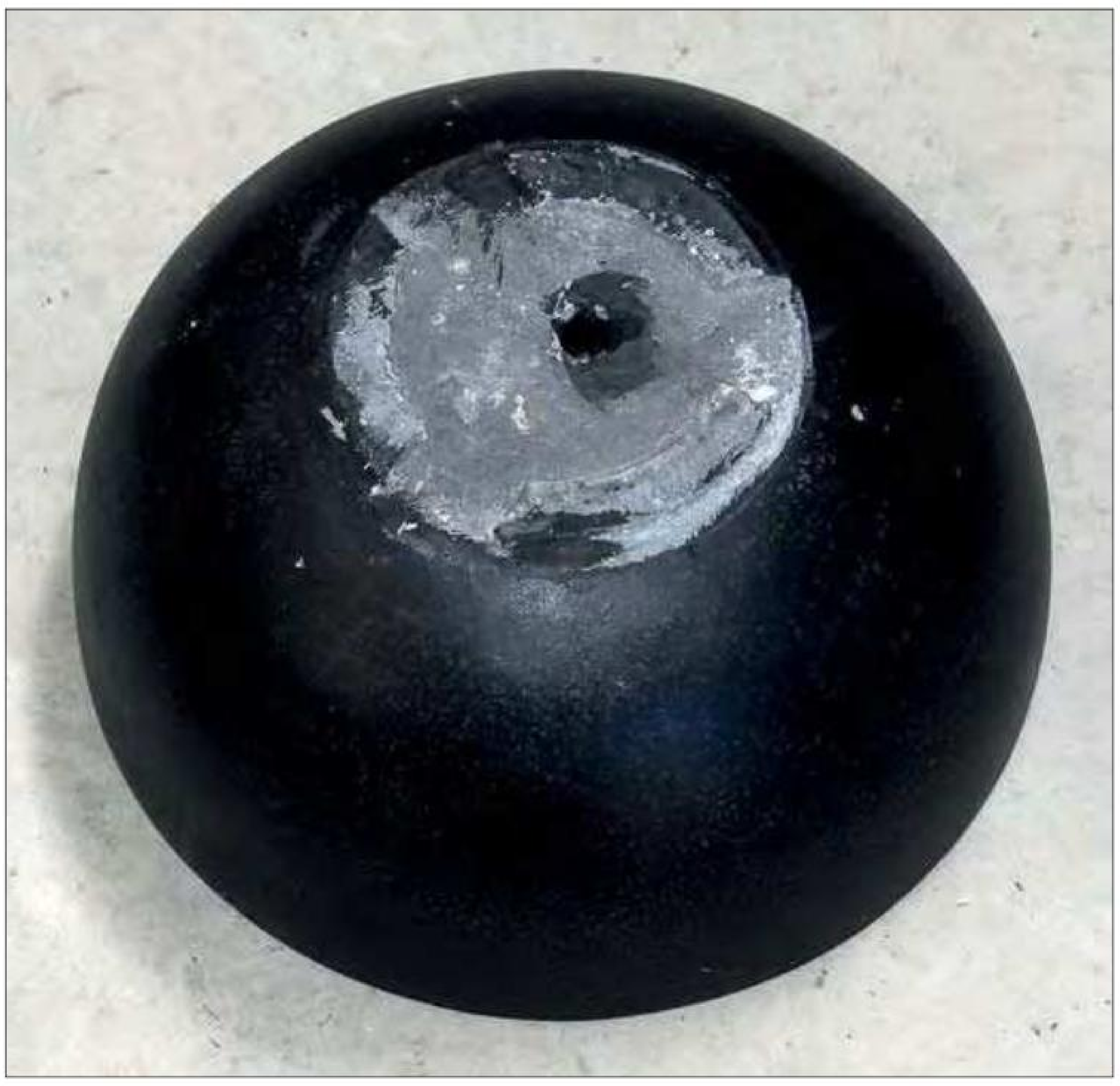


Fig.2. (above right) Here is the as-bought bowl turned upside-down. While it isn't super clear in this pic, the bowl rests on 'feet' which are formed into the bowl. To gain a flat surface, these feet need to be ground off.

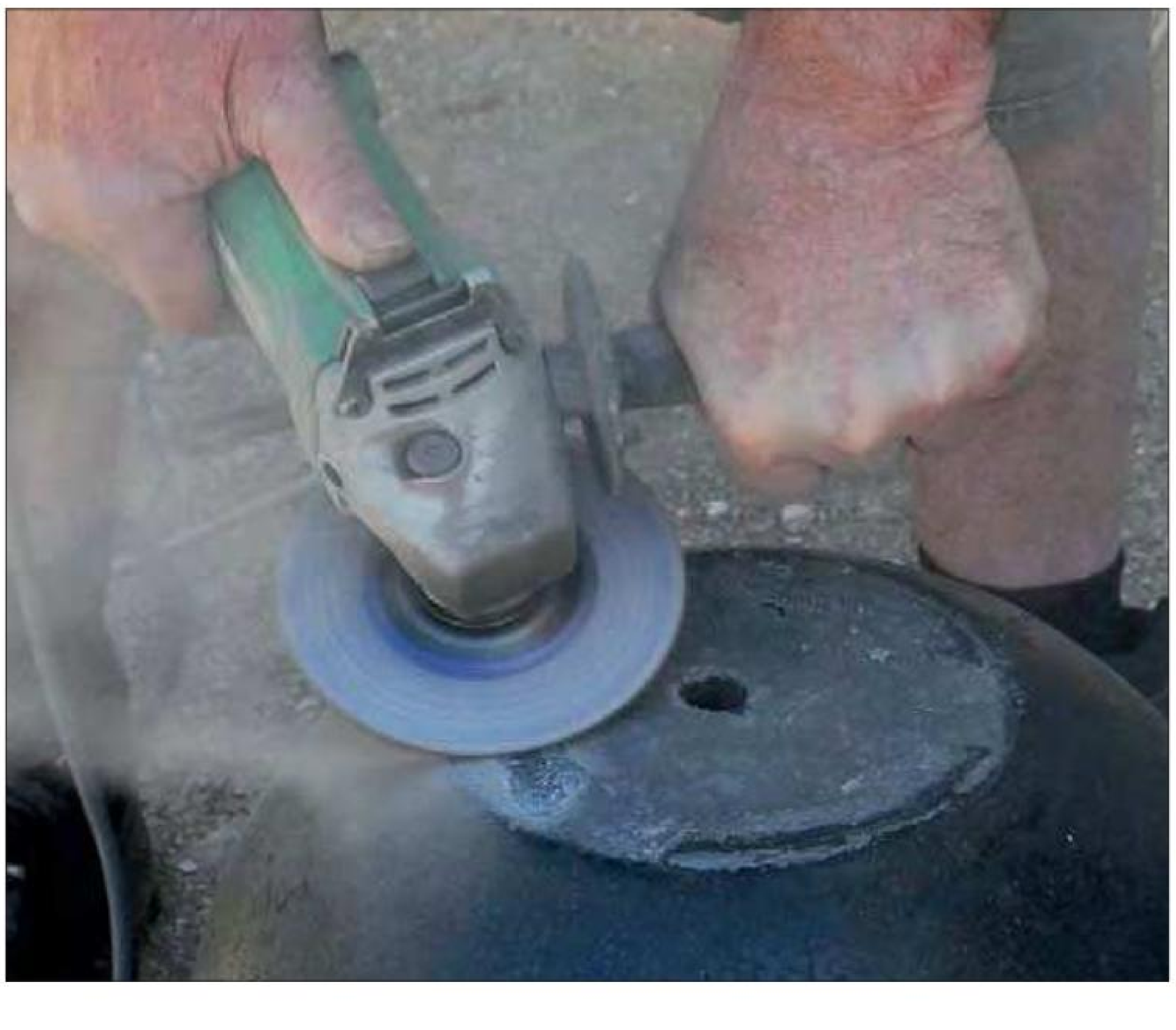


Fig.3. (opposite) A normal metal grinding disc mounted in an angle grinder does a good job of removing the 'feet'. Again, it's a dusty job and so it's best done outside with the operator wearing goggles, hearing protection and a dust mask.

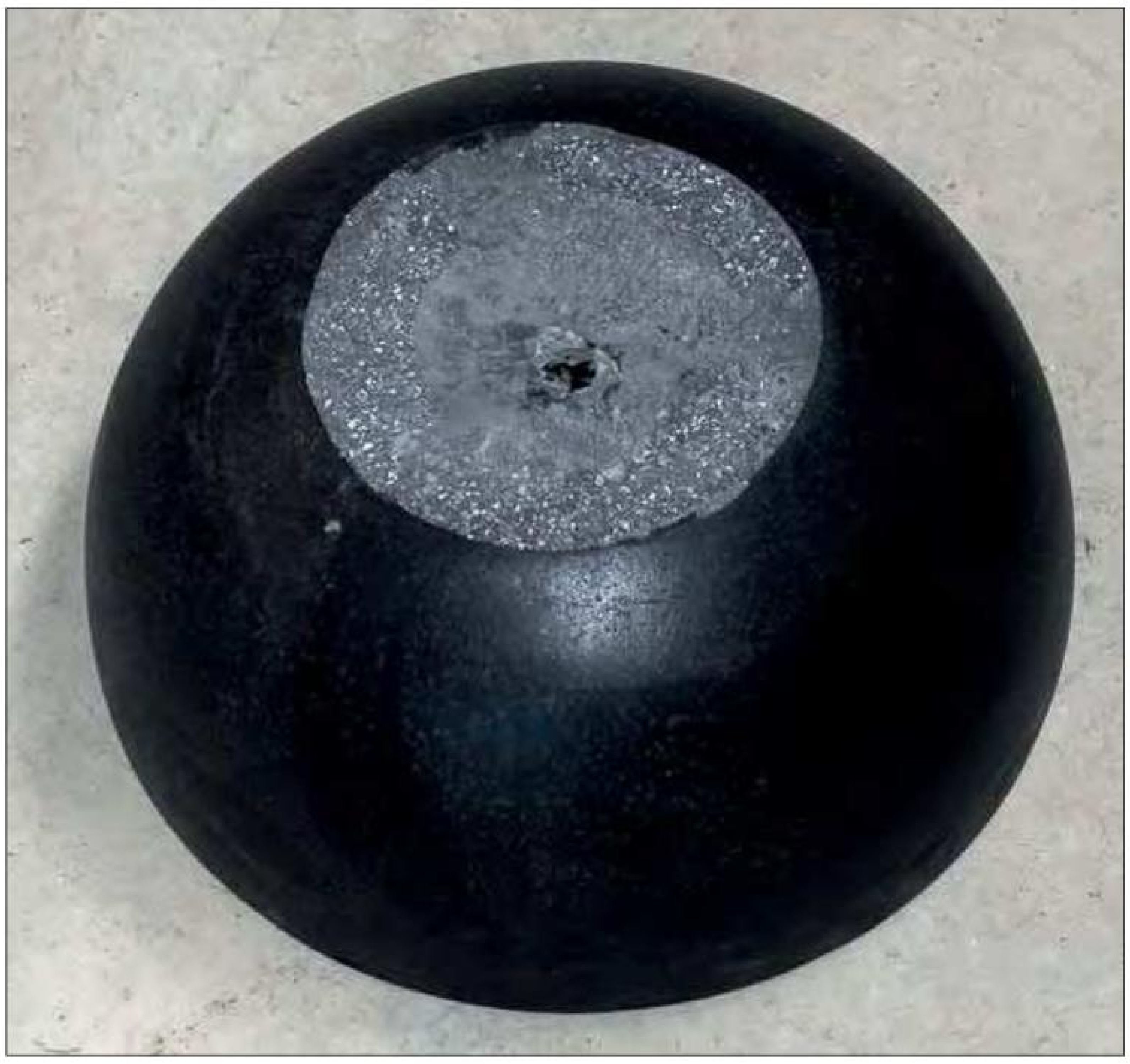


Fig.4. Here's the view with the base smoothed. To get it as flat as possible, follow-up the grinder with the use of a belt sander, or moderately coarse sandpaper and a sanding block.

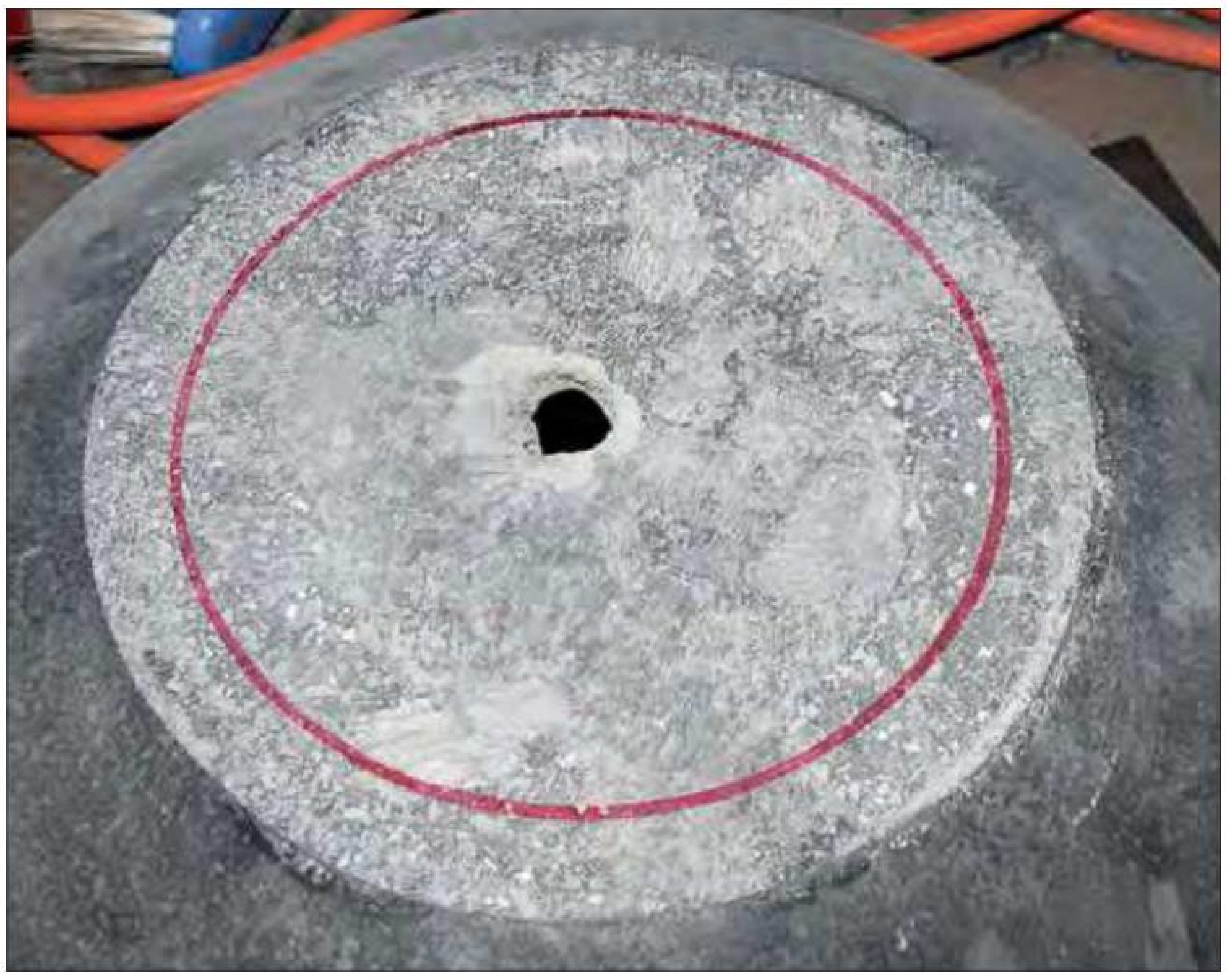


Fig.5. The next step is to mark the cut-out required for the driver. Be careful in sizing this hole – too small and there will be the need for lots of further grinding; too large and you will not get the driver to seal in the hole. Note the pot drainage hole.

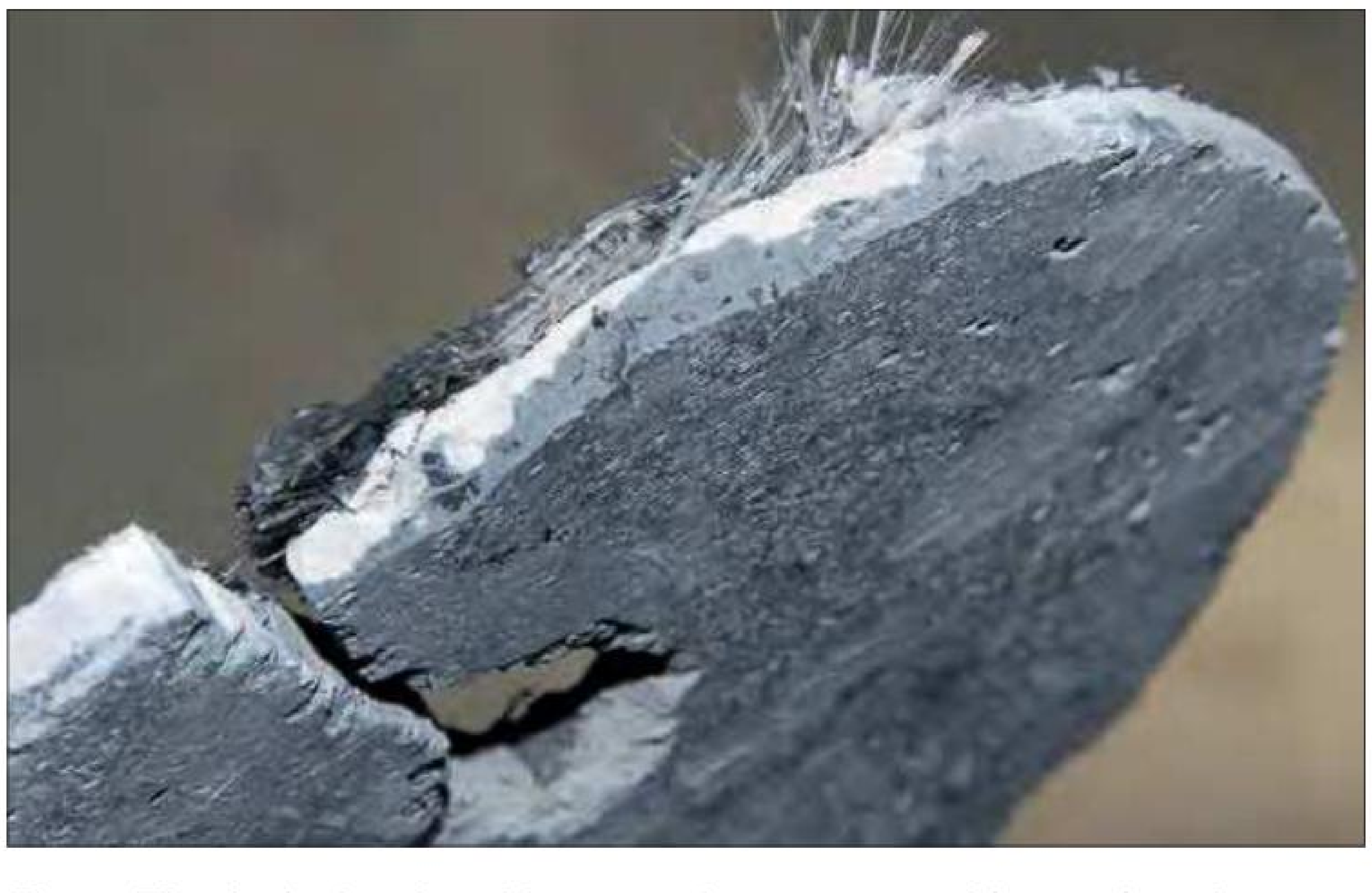


Fig.6. The hole for the driver can be cut out with an electric jigsaw – this pic shows the piece that's been removed. Use a coarse wood-cutting blade – and expect to get only a few holes out of the blade before it is blunt. Don't go like a bull in a china shop – you can crack the bowl if you push too hard.

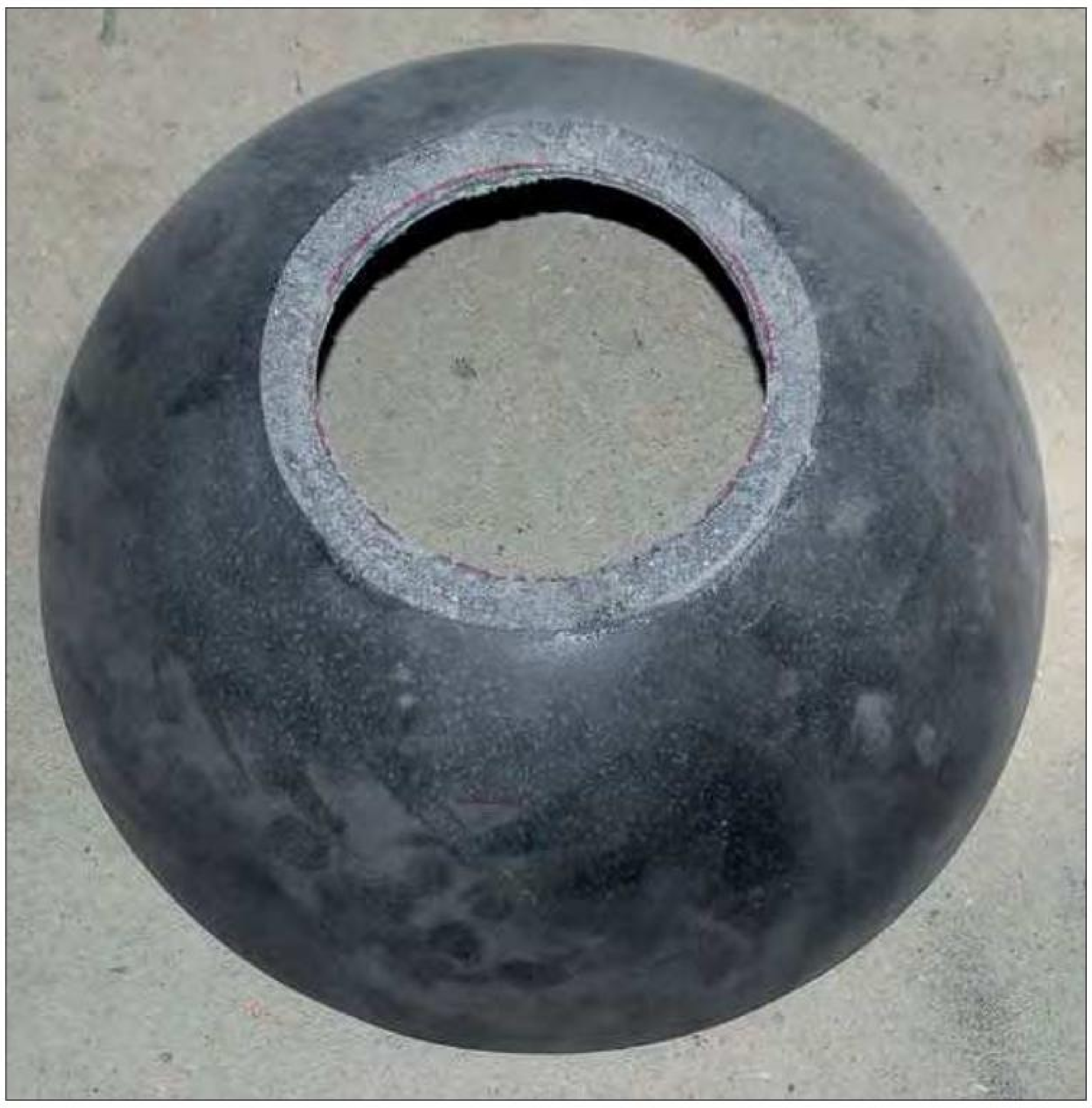


Fig.7. Here is the hole immediately after the jigsawing had been done. It's difficult in the clay-fibre mix to follow the line accurately (there are small pebbles in the material too), so it's better to err on the side of undersize rather than oversize. The hole can then be ground back to the line by carefully using the angle grinder or a half-round file.

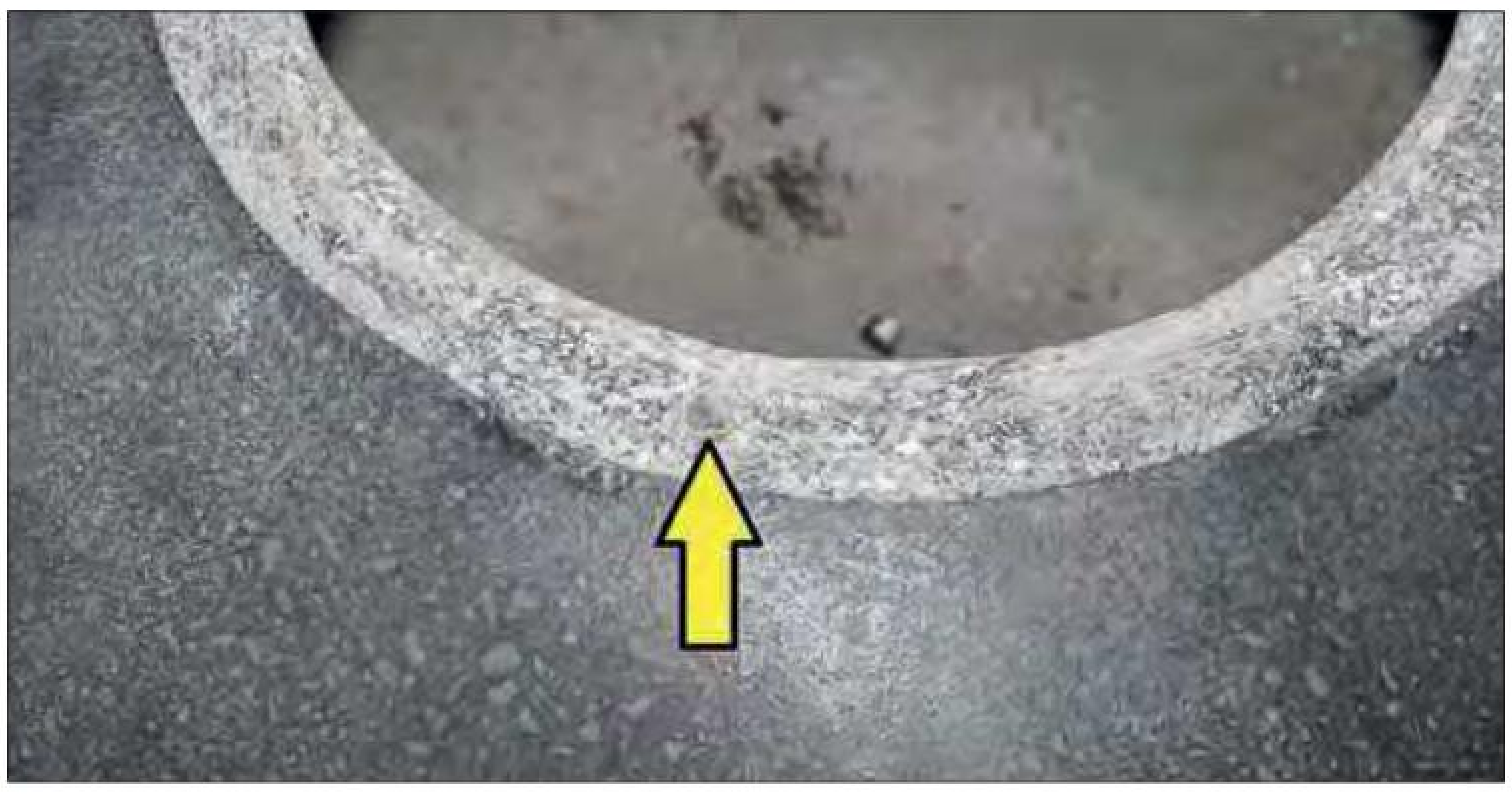


Fig.8. It's hard to see, but the arrow points to one of the speaker mounting holes that has been drilled. If you have a masonry drill bit, you could use that (not with a hammer drill!) but these holes were drilled with a normal HSS (high-speed steel) bit. Drill the holes sufficiently large that machine screws can be inserted – nyloc nuts and washers will go on the inside of the bowl.

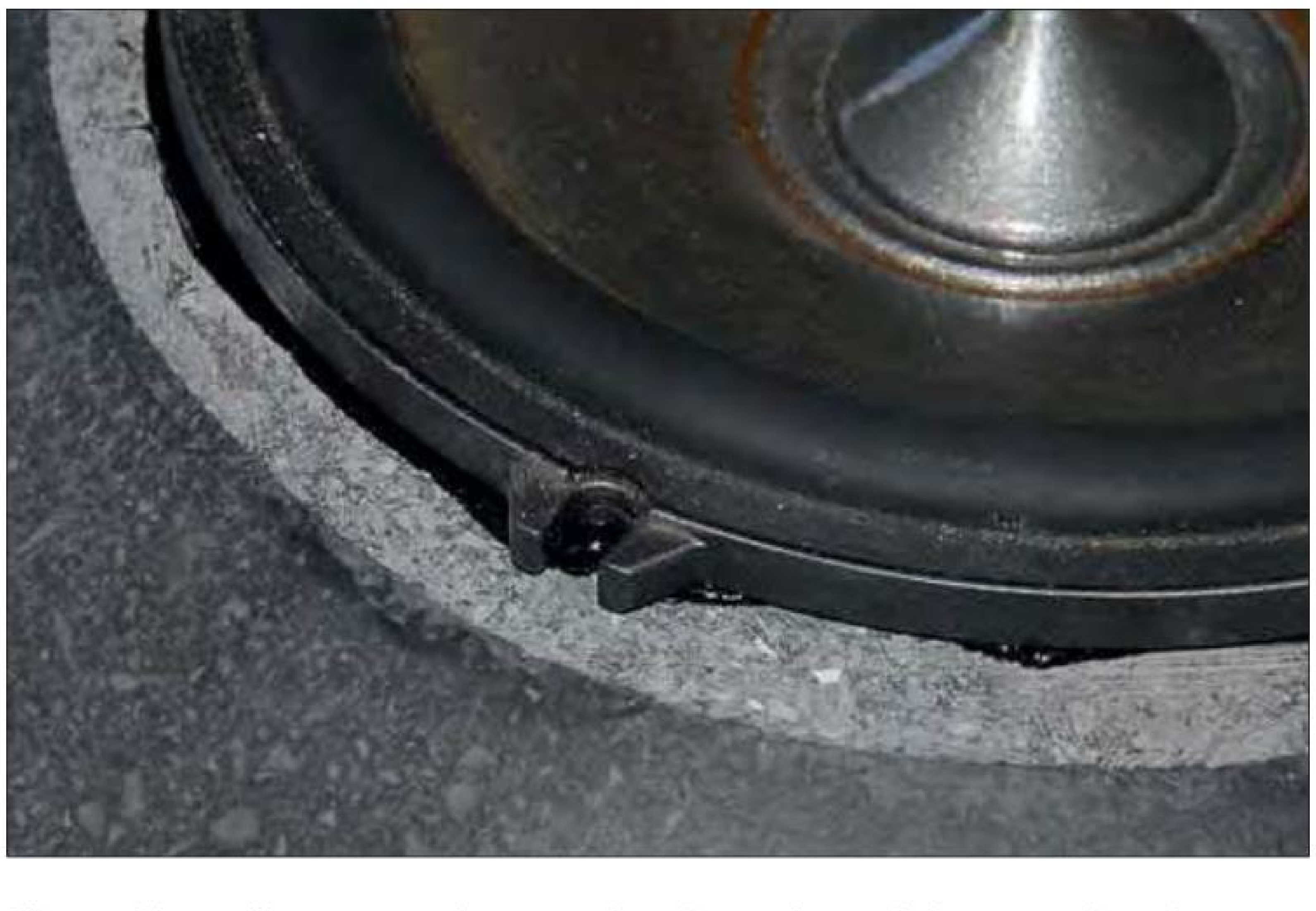


Fig.9. Use silicone sealant under the edge of the speaker frame. This is important because despite smoothing with the grinder and sandpaper, the mounting surface is likely to not be perfectly flat. You don't want air leaks around the edge of the driver.

– Flowerpot speaker acoustic design –

The complete acoustic design of loudspeaker systems is well beyond this article – however, here are some tips.

The most critical component to get right in terms of enclosure sizing is the woofer. Woofers are available with Thiele-Small specifications, and there are free online calculators into which these specs can be plugged. The software will quickly show you the required enclosure volume, and whether it is better that it be sealed or ported. (And in ported designs, the software will also show you the required diameter and length of the port.)

Note that the easiest way of measuring the internal volume of the pot is to fill it with sand, measuring the required volume of the sand with a measuring jug. (If using two pots, obviously double this volume.)

Thiele parameters

If you would like to measure the Thiele-Small specs of the driver yourself (perhaps you have an unknown driver for which the specs are not available) I recommend Woofer Tester 2, a combination hardware/software package that connects to a PC and allows quick and easy driver testing and enclosure modelling. I reviewed this package in the May 2017 issue of *EPE*/*PE*.

However, probably the easiest (and potentially cheapest) way of sourcing decent drivers, crossovers and an enclosure design, is to buy a good quality second-hand pair of speakers close to the enclosure volume you are chasing. If the particle board cabinets are a bit knocked around, you can pay very little for such speakers. You then just transfer everything (woofer, tweeter, crossover, port and terminal block) into the flowerpot enclosure. With the added wadding and usually acoustically better enclosure, the sound is very likely to be improved over the original – and of course, the speakers will look stunning.

In the enclosure design you can see here, I used Alpine SPR-17S 6.5-inch Type R Component Splits – these are sold for use in cars. This set comprises nominal 6.5-inch woofers with cast alloy frames, 1-inch dome tweeters, and full crossovers (not just capacitors).

The bass drivers lend themselves to compact ported enclosures, and the crossovers have variable tweeter attenuation so you can tweak the high-end response as you wish. The drivers also have plenty of power handling and, since in ported enclosures their efficiency is fairly high, lots of sound volume is available. At the opposite end of the spectrum, they also still sound good with only a few watts powering them.

The enclosures have an internal volume of 16 litres and are tuned to 49Hz, with a port 50mm in diameter and 118mm long. The tweeter is mounted below the main enclosure, and the crossover and port are mounted on the rear.

The sound of the finished speakers is outstanding – especially in their transparency and their ability for the vocalist to be ‘with you in the room’.

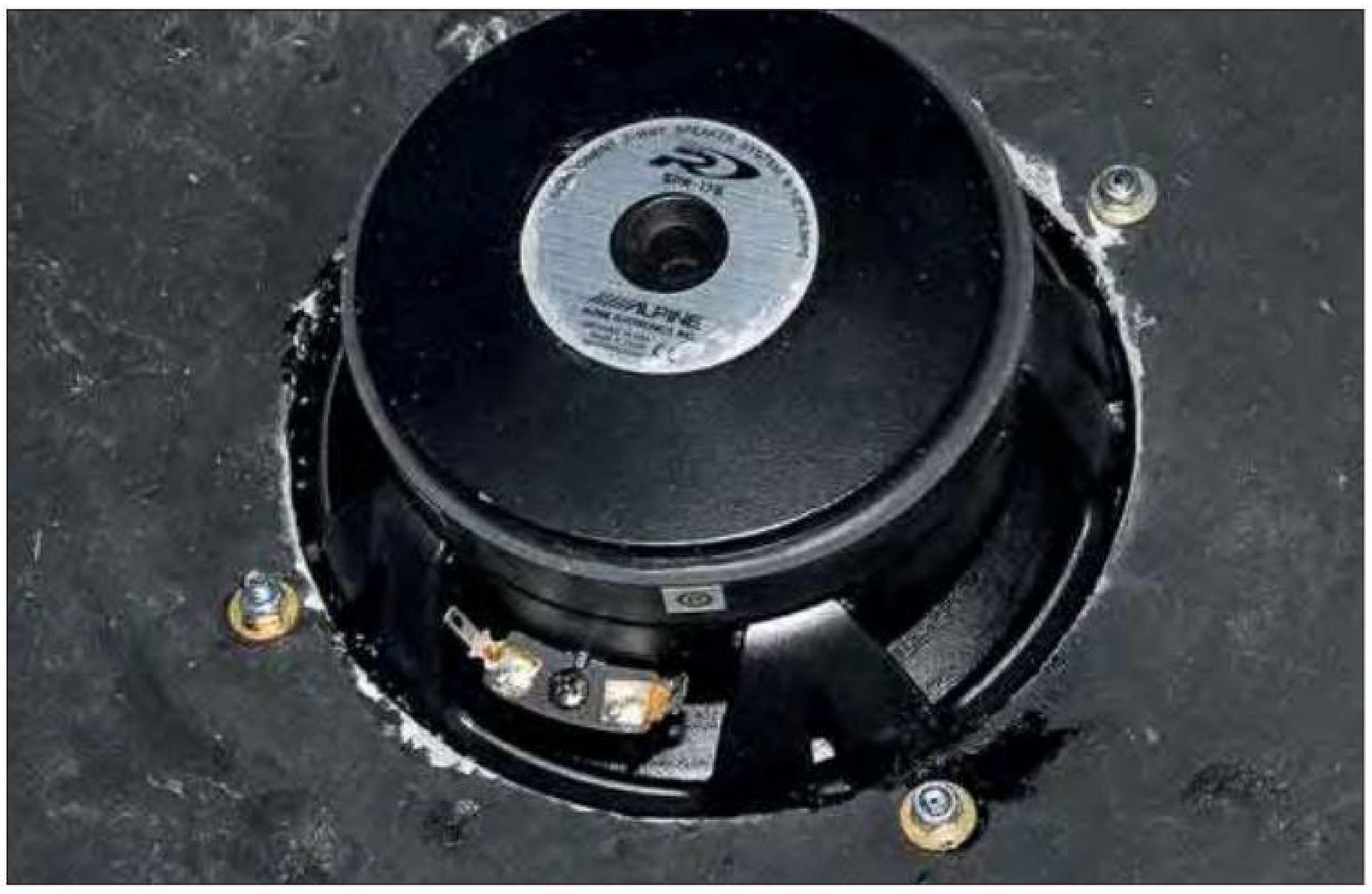


Fig.10. The driver installed in the hole. Note the use of washers and nyloc nuts on the speaker mounting screws. Tighten these when the sealant is yet to set – but be careful not to over-tighten or you could crack the bowl.

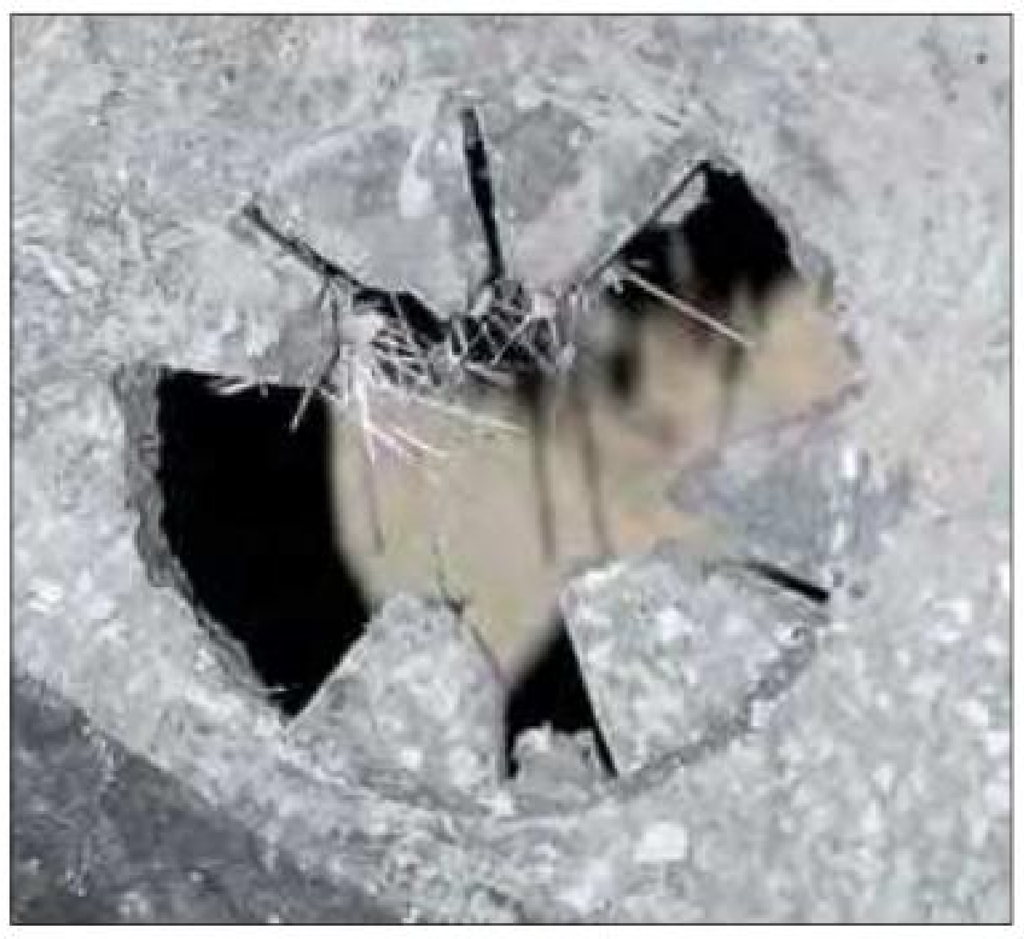


Fig.11. With the driver installed, it’s time to tackle the other bowl. The other bowl, its ‘feet’ already ground off, needs a hole made for the port tube. I found the easiest way to do this was to use the jigsaw to cut a series of radial slots like this, with the pieces then broken off by the careful use of pliers. The hole was then filed to final shape. The hole doesn’t have to be perfect – the industrial glue used to secure the port in place will fill any small gaps. (Don’t use an expensive holesaw to make this opening – the teeth will soon be blunt and the holesaw ruined.)

Fig.12. The port tube needs to be the correct diameter and length to match the enclosure design. PVC pipe is cheap and easy. This port is 50mm in diameter and 118mm long.

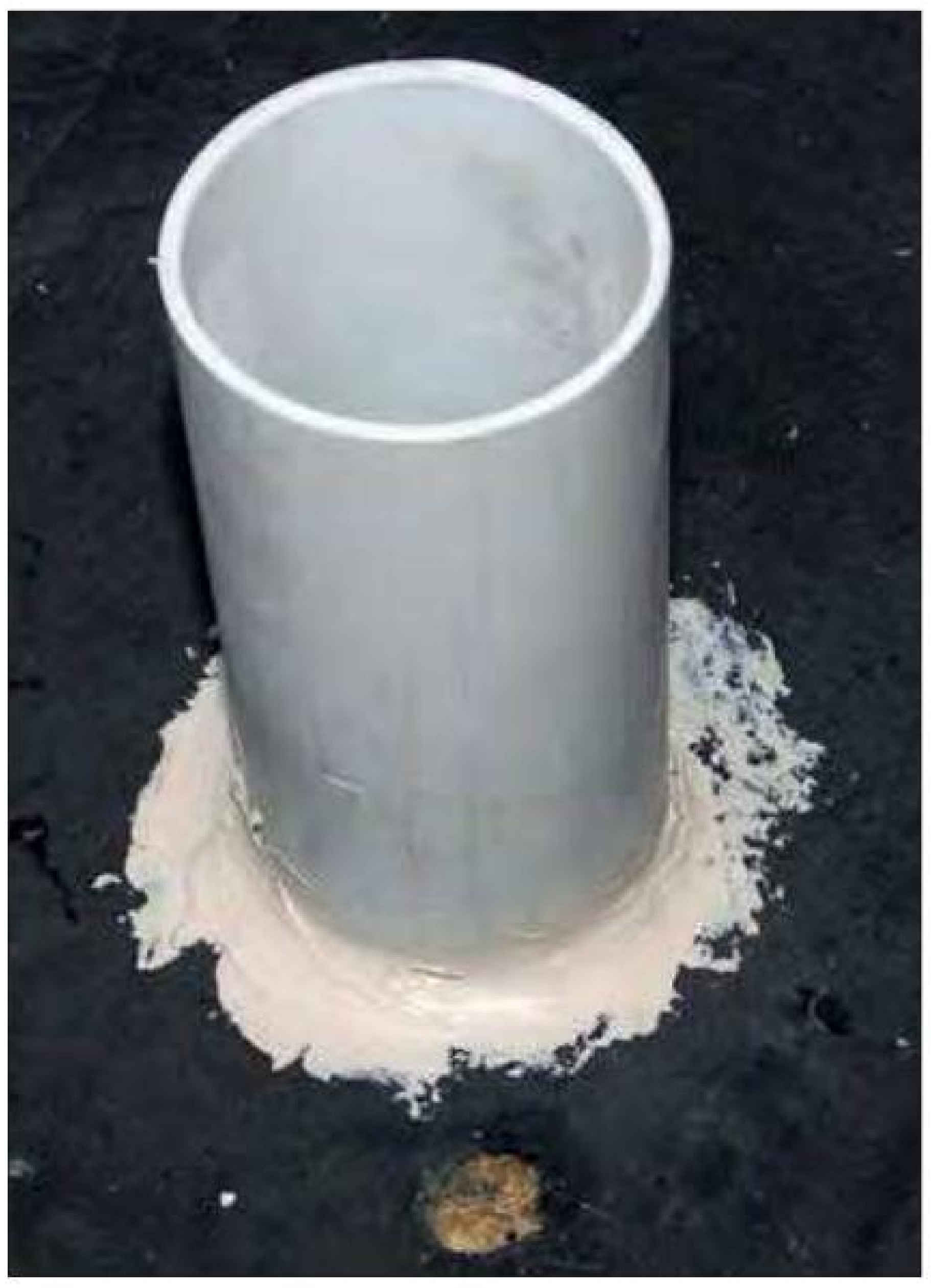


Fig.13. The port glued into place. For this task, and also gluing the bowl halves together, I used water clean-up Liquid Nails. Note that this glue was also used to seal the ‘water drainage hole’ provided in the original bowl.

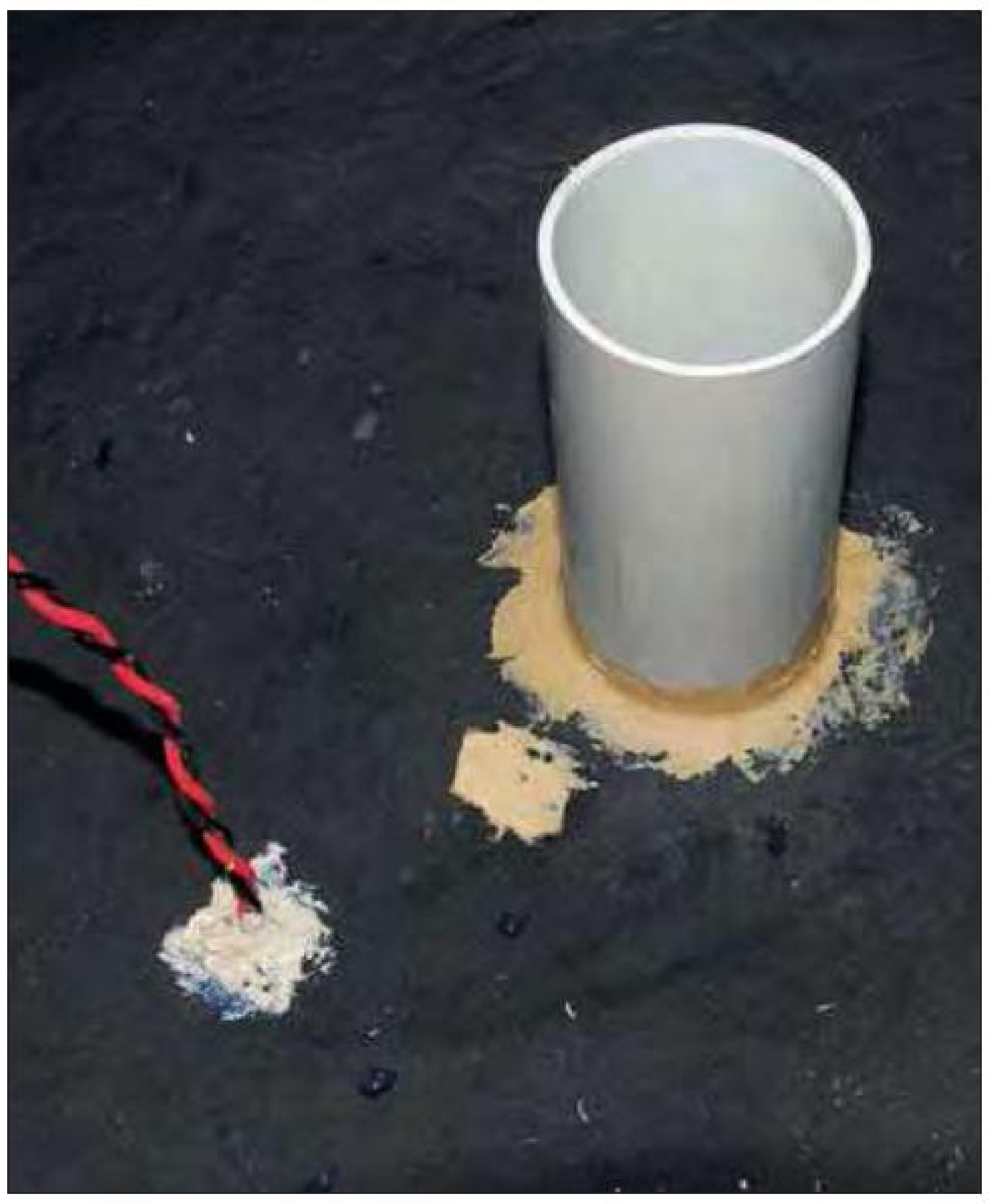


Fig.14. Now is also the time to feed the cable through a hole drilled in the bowl, and seal it with further glue. Either solder the wires to the woofer's terminals or equip the cable with push-on terminals to make this connection.
I chose to mount the crossover on the rear of the enclosure, but it could also be mounted inside.

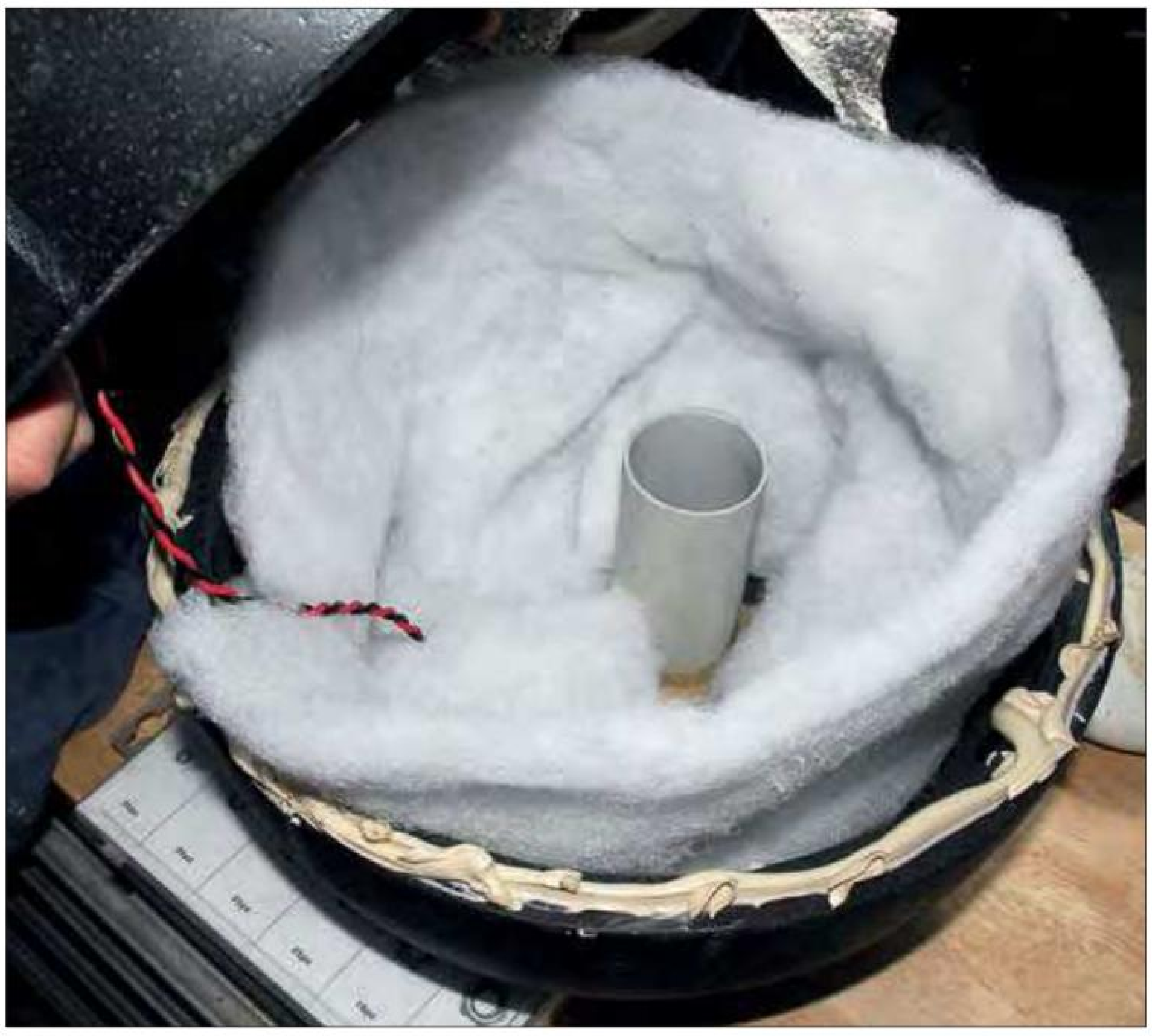


Fig.15. This photo shows two steps. The first is that polyester quilt wadding has been placed around the inside of the lower bowl. Ensure that there is enough projecting upwards from the lower bowl so that when the two bowls are glued together, the wadding covers the inside surfaces of the upper bowl as well. Also ensure the rear of the driver and the port are not blocked by the wadding. The second step is to glue the two halves together. Use a generous amount of glue around the rim of the lower bowl. The upper bowl is then carefully lowered over the lower bowl, ensuring the wadding goes inside the upper bowl as it is lowered. (This job is best done by two people.)

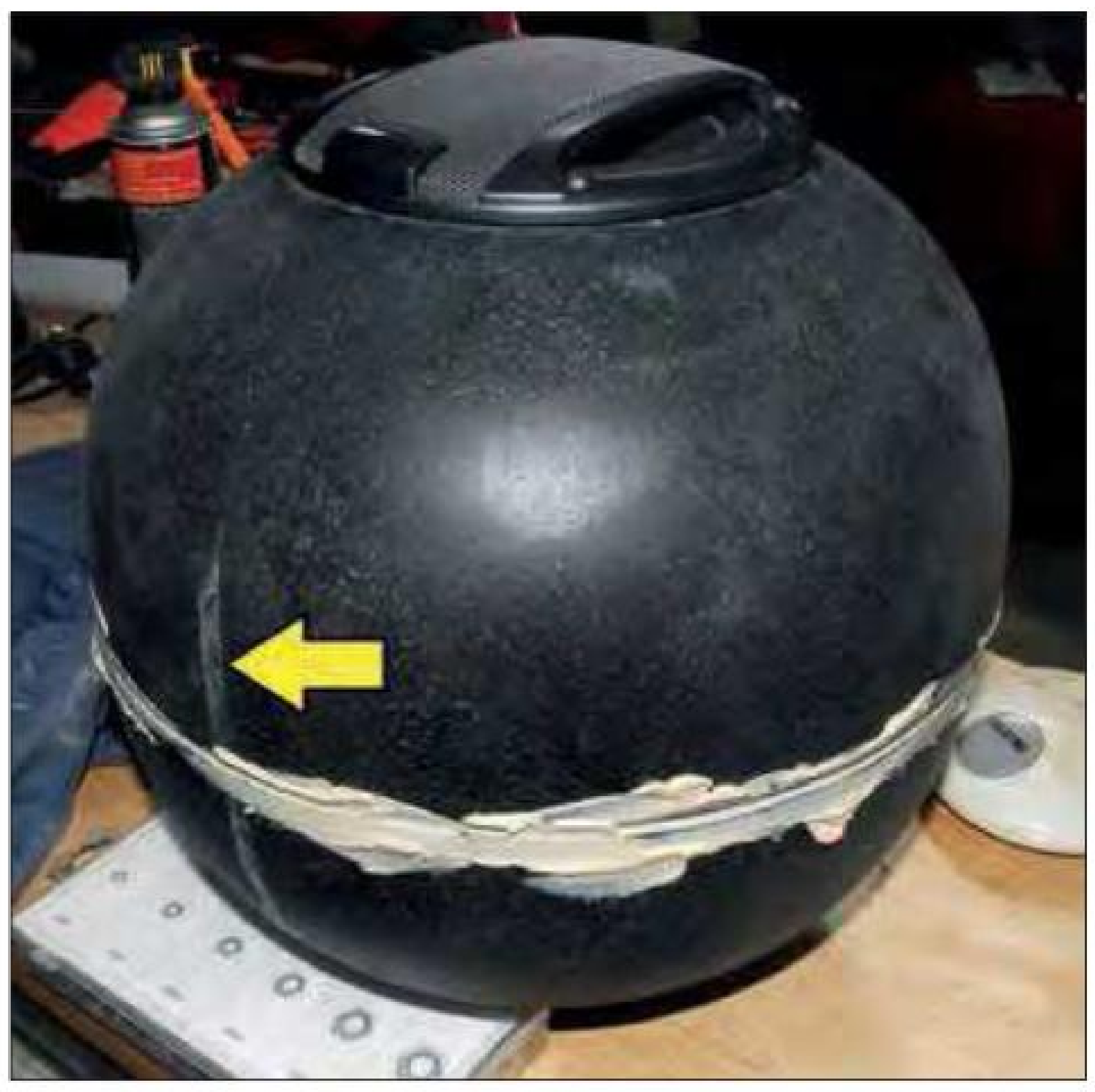


Fig.16. The bowls are pushed together and then a wet finger used to smear the glue around the join, ensuring that the gap is filled. A damp cloth is then used to carefully remove the surplus glue. (The glue must be of the water clean-up type!) Note the chalk witness line (arrowed) that shows the correct alignment of the bowls as they are joined. This line is made earlier when the best rotational fit is found – because their lips aren't dead-flat, the bowls fit together better in some orientations than others.

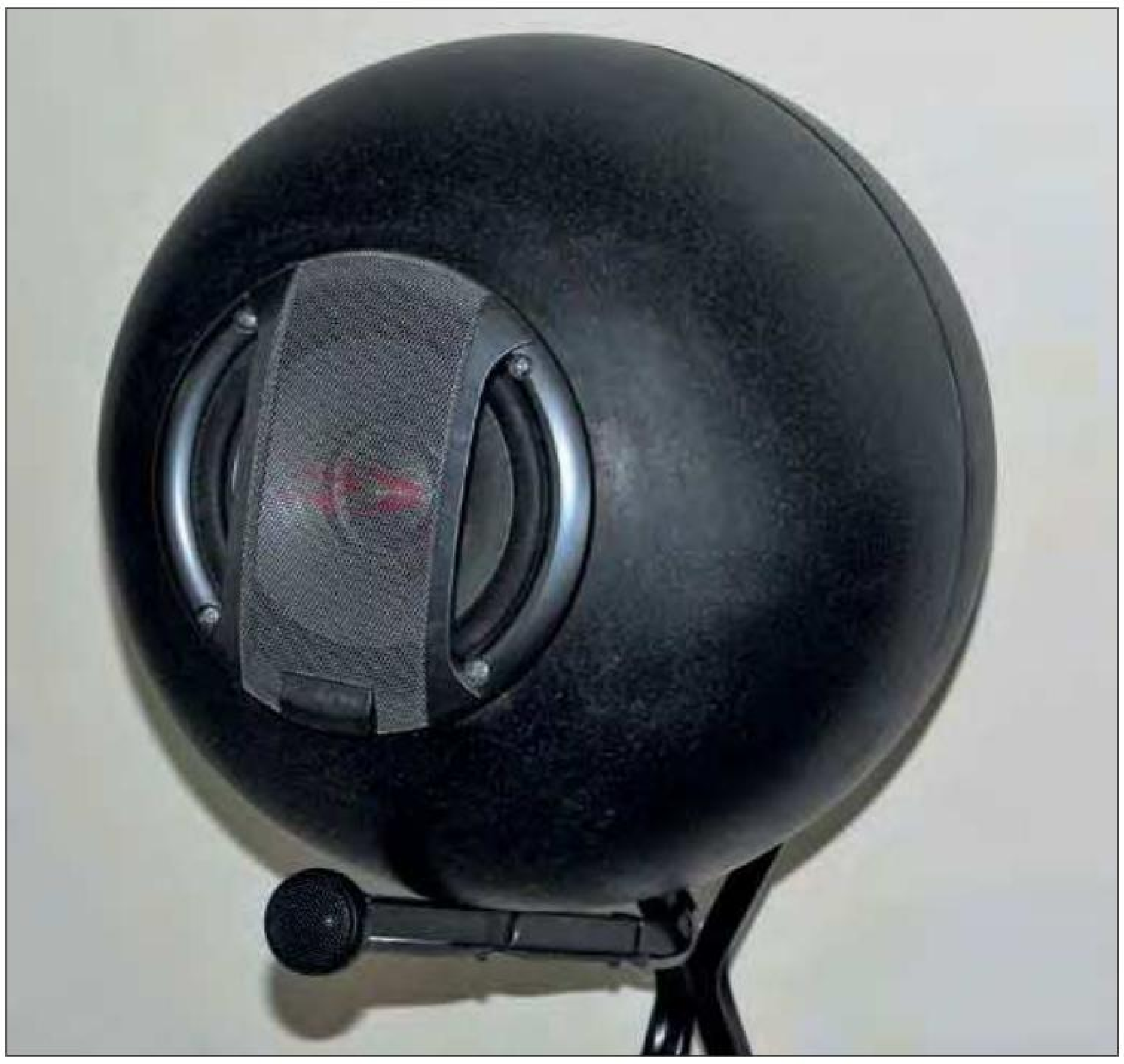


Fig.17. The tweeter is mounted below the main enclosure. I could have run the tweeter cable within the square tube, but in normal use the cable is not as visible as it is here. The physical position of the tweeter makes a substantial difference to the sound – it must be as far forward as the main driver.

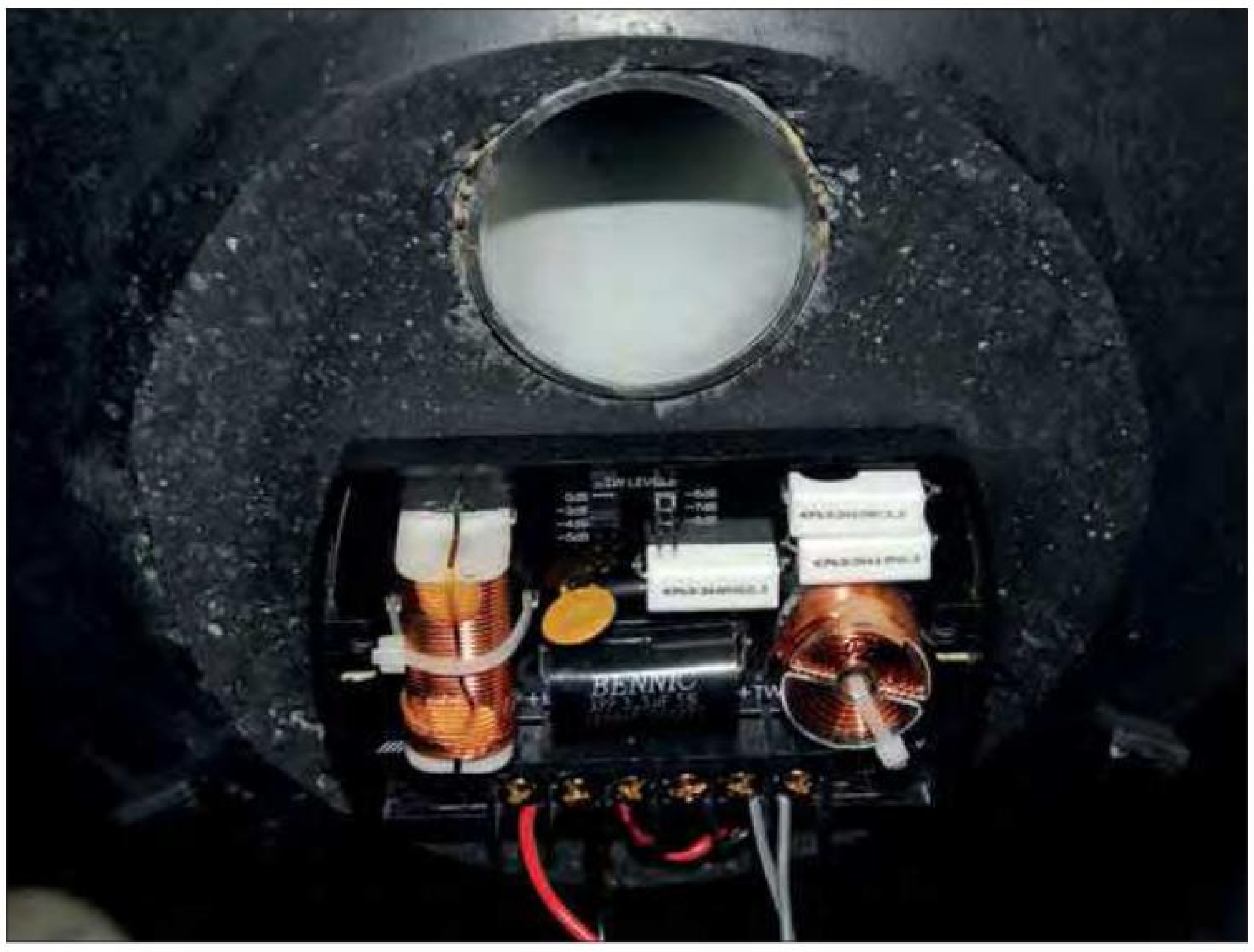


Fig.18. (above) The next step is to mount the crossovers on the rear 'flat'. The crossover was glued into position just below the port.

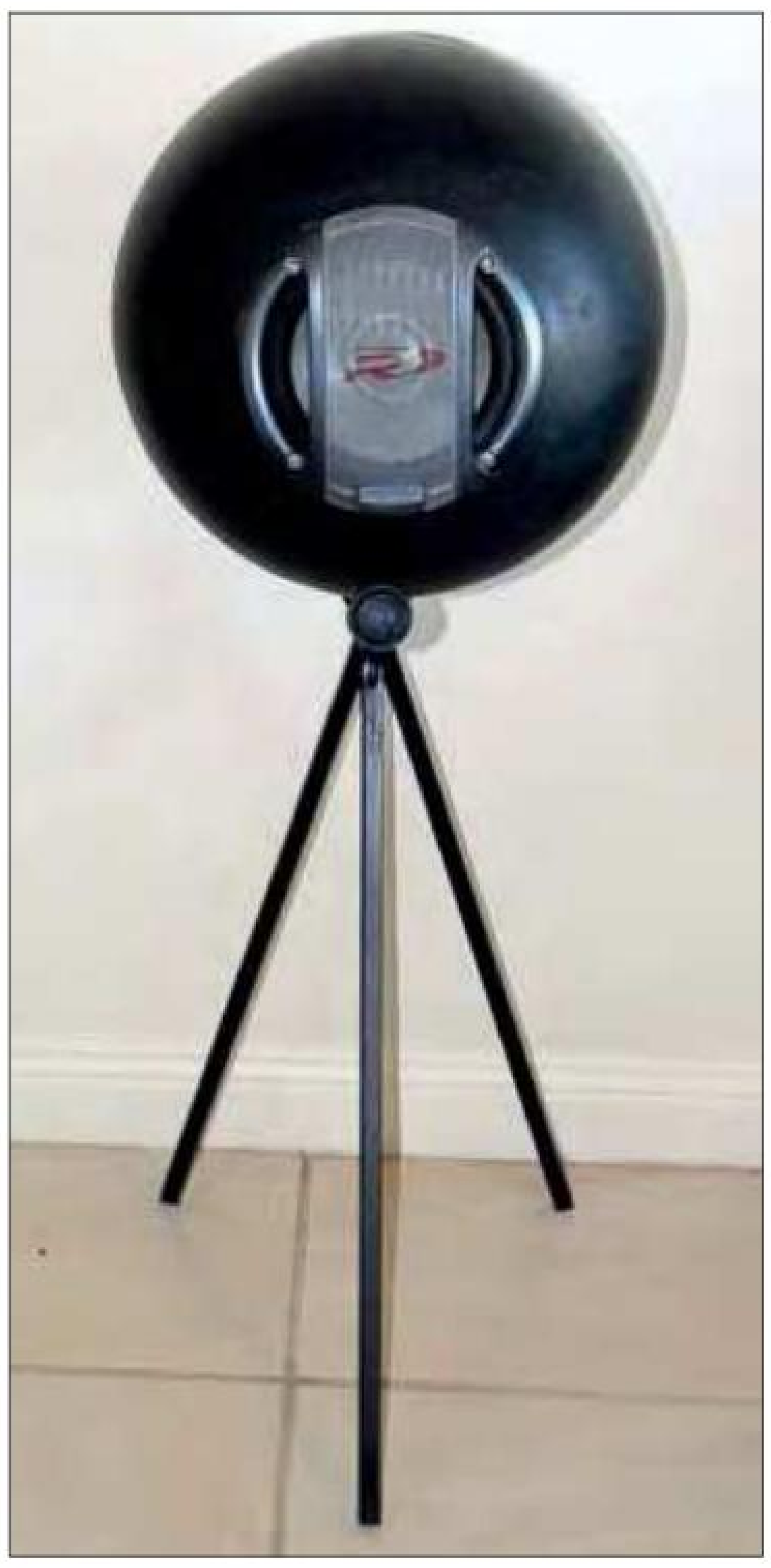
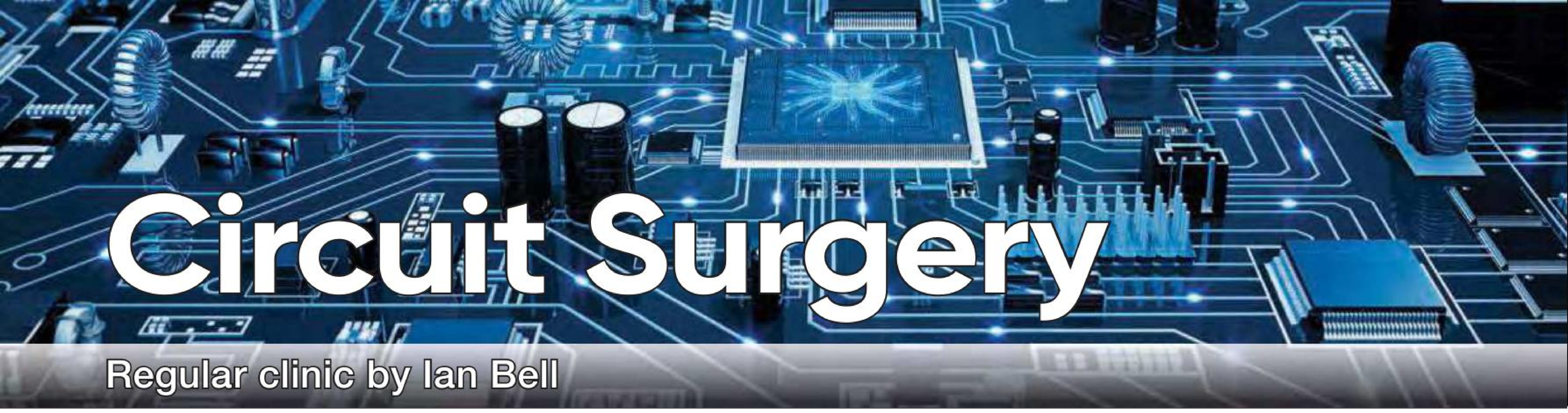


Fig.19. (right) The stand shown here was made from square tube. You can make any type of stand you wish – but the speaker must be off the ground to work at its best. (Also, when you are buying the pots, check out the available pot stands!)



Circuit Surgery

Regular clinic by Ian Bell

Differential amplifiers

Recently, on EEWeb's forum, Robinson-Constantin Chera posted a question asking about simulating an amplifier circuit, writing: 'I need to implement the following circuit [Fig.1] in LTspice but I don't know what V_{CM}, V_g, V_{CC} and *C* infinite are... Can you help me with the symbols for it?'

This is a basic operational amplifier (op amp) type circuit; or more specifically, the initial gain stages of an op amp without the power-amplifying output stage. The circuit is typical of those designed for implementation as integrated circuits (ICs), where transistors are used wherever possible and resistors are kept to a minimum. The amplifier only uses one resistor (R2) the other resistor in the schematic (R1) is a load and the capacitor (C_∞) is also part of the load. Circuits like this can look like an impossible mass of transistors if you are not familiar with the various building blocks which are used – so Fig.2 highlights the various sections.

The following outlines the circuit's structure (also refer to Fig.2) – if the terminology here is not all familiar, don't worry because we will explain its operation in more detail later. The amplifier has two stages. The first stage comprises a differential amplifier formed by Q1 and Q2, biased by the current source formed by Q6 and Q7, and connected to an active load formed by Q3 and Q4. Q6 and Q7 form a current mirror, with Q6 providing the reference for Q7 to deliver the bias current to the differential amplifier. The second stage is a common-emitter amplifier using Q5, for which Q8 is an active load. Q8 is a current source to provide bias and act as a high resistance load; like Q7 its reference is provided by Q6.

We discussed the common-emitter amplifier with active loads in a recent *Circuit Surgery* article (*PE*, December 2019) so we will focus on the differential amplifier in this article.

Spicing up the circuit

Robinson-Constantin posted a couple of LTspice schematics on the forum and received feedback. We will not look at those specifically, but will discuss some general issues about setting up this (and similar circuits) for simulation. The schematic in Fig.1 is a typical 'textbook' circuit (we will refer to it as such, although of course the source may be a web page). The aim of such circuits is often to explain operating principles, and some things may be left out to simplify the explanation or focus on a particular aspect, which may lead to problems with simulation. Textbook circuits may be idealised to facilitate a discussion of key points without getting bogged down in complexities.

SPICE can simulate highly idealised circuits, but the assumptions may not match reality, particularly with active devices such as transistors, which again, may cause problems. This will be more likely if 'real' transistors are used in the simulations (models of actual devices), as Robinson-Constantin did. Default models match NPN and PNP transistor characteristics, which is unlikely with real device models – the circuit may 'unbalance' and fail – typically one or more transistors may get stuck in saturation. Similar issues were discussed in the December 2019 article on active loads. Even the default transistor models may not give the desired results without some tweaking to match what is implied by any assumptions.

Before worrying about these things, you need to set up the schematic – copying the basic schematic from the textbook is probably straightforward, but you may need to add components

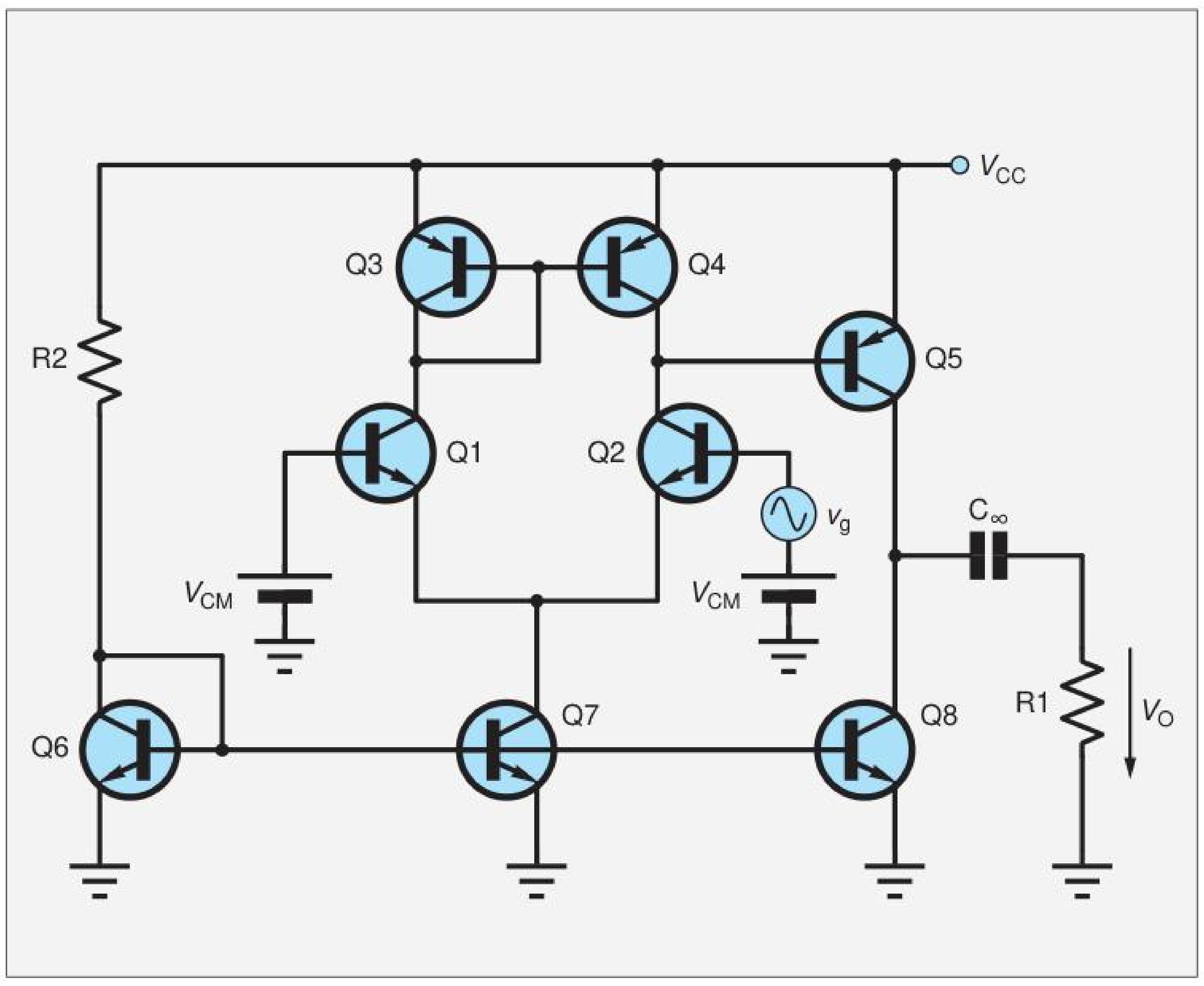


Fig.1. Robinson-Constantin Chera's amplifier circuit.

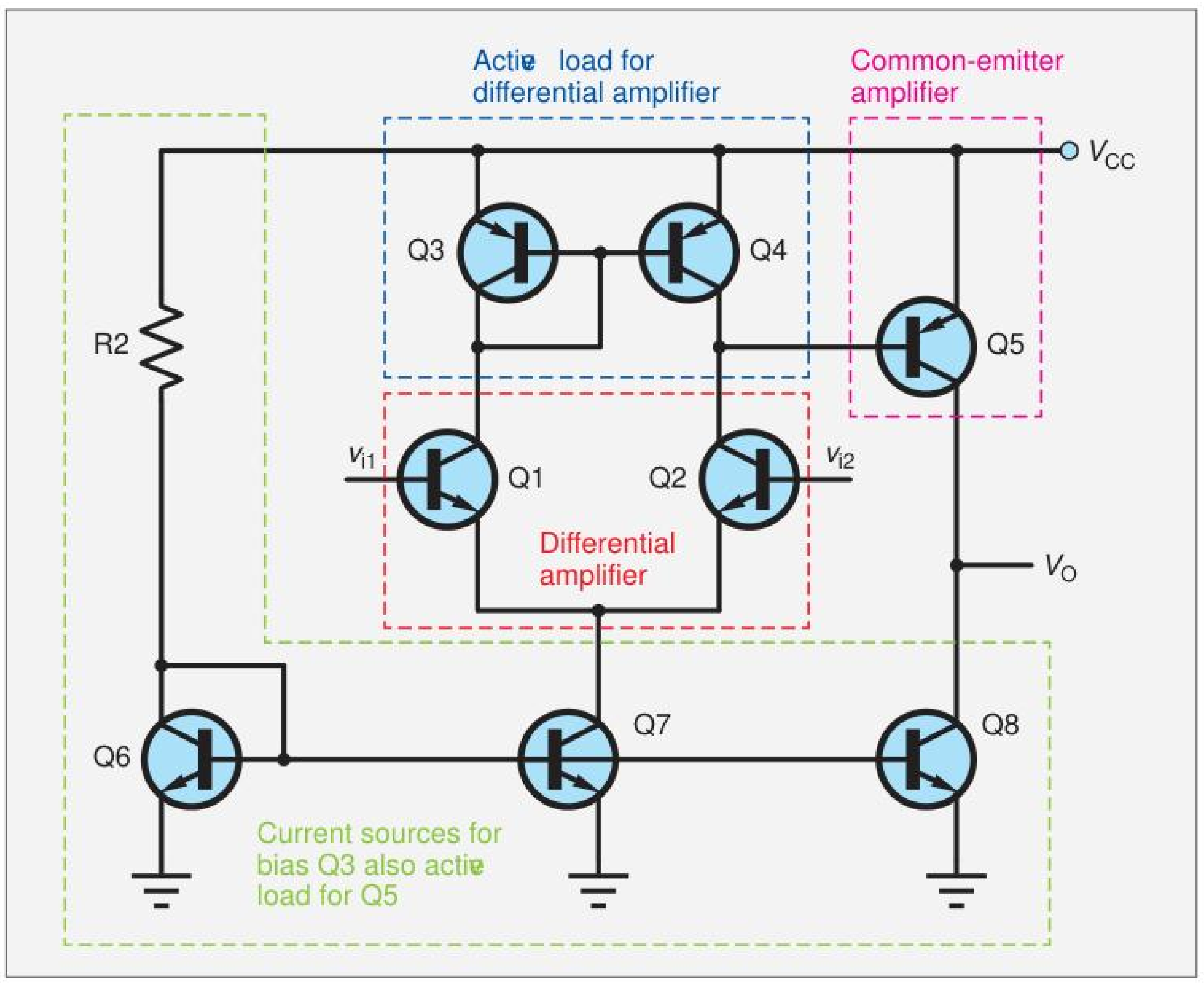


Fig.2. The circuit in Fig.1 with the various building blocks identified.

to account for the input signals, power supplies and loads. Robinson-Constantin asks about V_{CM}, V_g and V_{CC} – these are the inputs signal (V_{CM}, v_g) and supply (V_{CC}). The value of V_{CC} was not specified in the original post, but later 10V was used.

It is often a good idea to simulate circuits with a load, even if the value is idealised (eg, to a very large value) while the basic operation is confirmed. Changing the load's value will provide insight to the circuit's performance. In Fig.1, R1 is the load and C_∞ is a coupling capacitor which is chosen to have a much lower impedance than R1 at the frequencies of interest. If this condition is met then the specific value is generally not very important in a simulation.

In textbooks, supplies are often just labelled (eg, V_{CC} in Fig.1), but for a simulation you will need to put voltage sources on the schematic to account for each power supply – in this case there is only one, but split supplies are common, and some circuits have multiple supply voltages.

Differential signals

The circuit in Fig.1 is a differential amplifier, so it has two inputs and we can use two voltage sources in the simulation to set up the input signal. Differential signals are carried on two wires, so the signal of interest – the signal we want to amplify – is the voltage between the two wires. For example, this could be 1mV, but the individual voltages could be –0.5mV and +0.5mV or 1.9995V and 2.0005V, or an infinite number of other possibilities. The voltage difference does not completely describe the situation, we also need to specify the average value of the two voltages, called the common-mode voltage, which is 0V and 2V respectively in the two examples.

In Fig.1 the common-mode voltage is applied to the two inputs with two equal V_{CM} DC voltage sources. Having established the common-mode voltage, the wanted signal – the difference – can be applied using a signal voltage source on one of the inputs. Exactly the same setup can be used in the simulation, but actually only one SPICE voltage source needs to be use per input because one can be set to be DC at V_{CM} and the other to be a sinewave source of amplitude v_g with a DC offset of V_{CM}. Alternatively, we can use two DC-plus-sine sources with 180°-out-of-phase sinewaves of the same frequency and half the amplitude of the desired differential input signal.

Differential-input circuits such as op amps can only operate over a limited range of common-mode voltages, and the circuit in Fig.1 is no exception. We must use a suitable value and 0V might seem like a simple option, but it will not work for Fig.1. Unlike many basic op amp examples, which use a split positive and negative supply with 0V in the middle, the circuit in Fig.1 operates on a single supply, so V_{CM} = 0V would switch off the transistors in the amplifier – it would not work. We need V_{CM} to be about half the supply voltage for optimal operation. Similarly, we need to set a suitable value for v_g, which we will discuss later.

Current sources

As indicated above, in ICs, circuits based on transistors are typically more economical and provide better performance than using resistors. Basic transistor amplifiers use resistors (for example, a potential divider connected to the base) to set the operating point – the current flowing in the transistor with no signal present. Instead of using resistors, the operating point can be set by using a circuit which sets up a constant current, equal to the operating point current, into the transistor. During operation the transistor's total current will vary around this point as the signal changes, just as it does with resistor-based biasing.

The circuit in Fig.1 uses a basic current source – a two-transistor current mirror, as shown in Fig.3, where the transistors have been labelled to match their role in Fig.1. The base-emitter voltages (V_{BE}) of the two transistors are exactly equal because they are connected directly together, so if the transistors are identical, and have the same environmental conditions (in particularly their temperatures are equal), then the currents in both devices, which are controlled by V_{BE}, must be equal. It follows that two currents I_{In} and I_{copy} in Fig.3 are *almost* equal. They are not exactly equal because some of I_{In} is diverted to provide the base currents, but this is typically a very small proportion (typically 1/50 to /100 or less), so values are very close. If we apply a current (I_{In}) to Q1 we get the same current flowing in Q2, thus the circuit can copy, or 'mirror', a current from one part of a circuit to another.

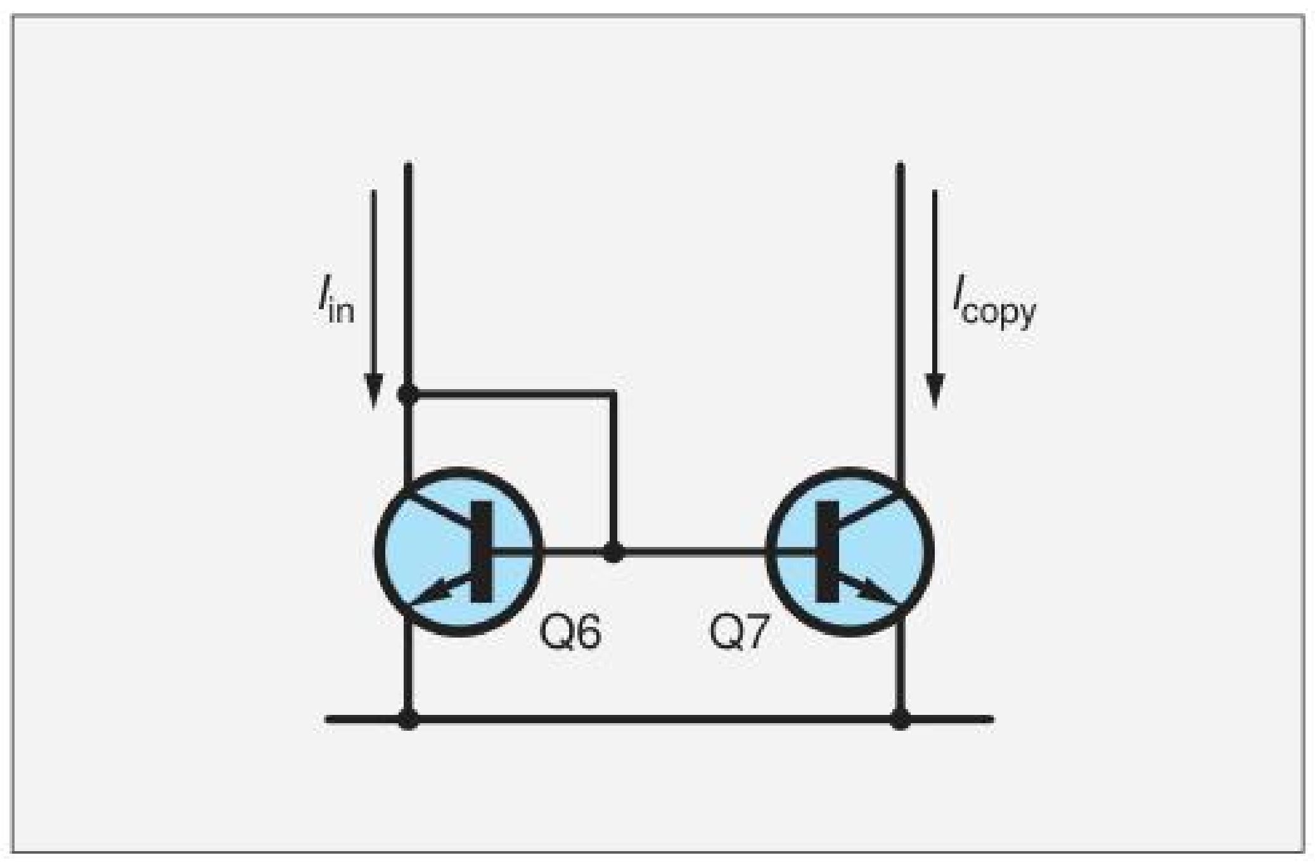


Fig.3. The basic matched-transistor current mirror.

Transistors with identical characteristics and environment are referred to as 'matched'. They are often used in IC designs, where designers can use layout techniques to ensure the transistors are closely matched. For discrete designs, matched transistors in a single package are available.

In the circuit in Fig.3, Q6 is 'diode connected' – the base and collector are shorted so the transistor acts as a diode (the base-emitter junction). It is easy to establish a fixed current in Q6 by connecting the collector to a fixed voltage via a resistor – exactly as in Fig.1, where the collector of Q6 is connected to the supply via R2. This will fix the V_{BE} of Q6 and Q7 and cause a fixed current to flow in Q7 (I_{out}). Thus, Q7 acts like a constant-current source with one end connected to ground.

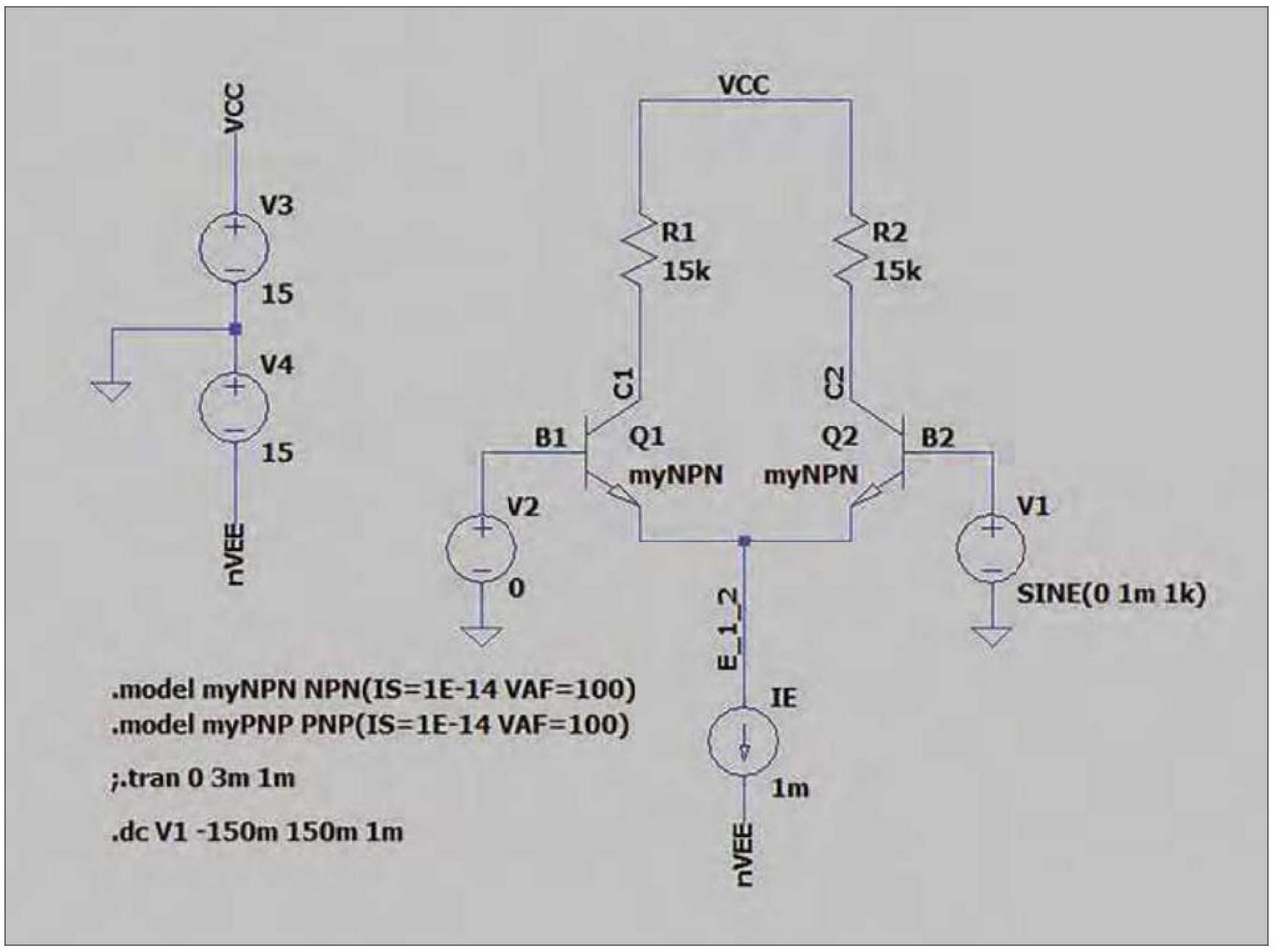
As just discussed, Q6 and R2 provides the reference V_{BE} to set the current in Q7. Within reason, we can connect more transistors in the same way and get further copies of the reference current in Q6. This is done in the circuit in Fig.1 – Q8 provides a second copy of the reference current. Transistors can only be added 'within reason' because each diverts more base current from the reference and makes it more difficult to ensure they are all matched.

Differential amplifier

When investigating a circuit with multiple blocks it can be useful to simulate individual sections. The circuit for an LTspice simulation of just a basic differential amplifier is shown in Fig.4, this uses resistors instead of an active load to make it simpler (`R1` and `R2` in Fig.4 instead of Q3 and Q4 in Fig.1). Similarly, the bias is provided by an ideal current source rather than the circuit implementation in Fig.1. The circuit uses a ±15 V split power supply (`V3` and `V4`, to provide an illustration of this in LTspice, in contrast to the signal supply of Fig.1 (LTspice version shown later). The supply lines are `VCC` and $-V_{EE}$ (labelled as `nVEE`). The input signal has 0V common mode as this is the middle point of the split supply.

The circuit in Fig.4 uses a custom transistor model (`myNPN`) based on the default LTspice NPN model. Only two parameters are changed the saturation current (`IS`) and the Forward Early voltage (`VAF`). The default is `IS` = 1.0×10^{-16}A, but using 1.0×10^{-14}A brings the value closer to typical signal transistors. The key effect is to scale the base-emitter voltage to emitter current relationship, shifting the V_{BE} for a given collector current. We will look at Early voltage later.

Notice the symmetry of the differential amplifier – it is key to its operation



```
.model myNPN NPN(IS=1E-14 VAF=100)
.model myPNP PNP(IS=1E-14 VAF=100)
;.tran 0 3m 1m
.dc V1 -150m 150m 1m
```

Fig.4- Basic differential amplifier LTspice schematic.

– to achieve it the two transistors must be matched. It has two inputs (`B1` and `B2` on Fig.4) and two outputs (`C1` and `C2`, also on Fig.4). Small differences in the input voltages cause relatively large changes in the output voltages, also in a differential manner (ie, as one output voltage increases, the other will decrease by the same amount). We can, however, choose to use only one output ('single-ended' output). Key points to understanding the circuit's operation are: first, a transistor's collector and emitter currents are very sensitive to changes in base voltage; and second, the emitters are connected to a constant-current source (`IE`).

The constant-current source means that the sum of the two emitter currents must always be equal to `IE`. If the two base voltages are equal, and the transistors are exactly the same then it follows that `IE` will split equally between the two transistors; that is, they will draw the same base current, and their collector currents will be equal. Since the two collector resistors are equal the voltages dropped across them will also be equal (assuming there is no output current). If the two input voltages change together (a common-mode input signal) then the symmetry will not be disturbed, `IE` will still split equally between the two transistors. At first, though, it may seem that changing the input voltage must change the collector and emitter currents, but it does not have to because the emitter voltage is free to change, whereas `IE` is fixed by virtue of the constant-current source.

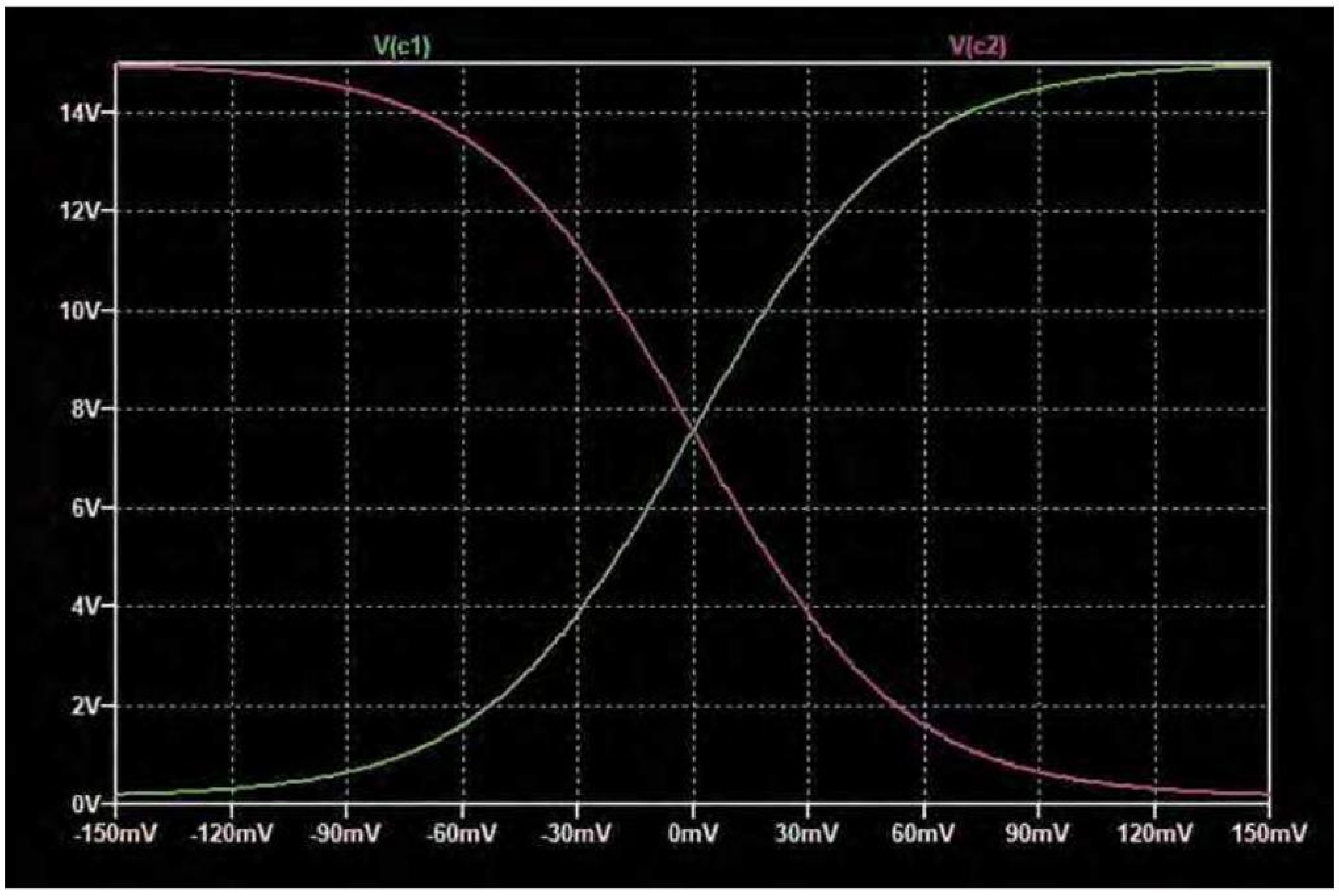


Fig.5. Plot of output voltages at the collectors vs input voltage difference (voltage between the bases) for the circuit in Fig.4.

The lack of response to common-mode inputs helps makes the design of very high-gain DC amplifiers possible. If the temperature of a single-transistor amplifier changes then the bias currents and voltages shift. In capacitively coupled (ie, AC) circuits this does not matter because the temperature changes are slow and are below the cut-off frequency due to the coupling capacitor. However, if there is no capacitive coupling then any changes in voltages due to temperature (or other forms of 'drift') are effectively indistinguishable from required low-frequency signals and will be amplified. If the temperature of a properly matched differential pair changes, however, both transistors are affected equally and there is no change in the output (the drift is a common-mode signal). The worst place to get drift is in the first stage, as the error is amplified by all subsequent stages; thus, having a differential pair as the first stage is a good way of reducing overall drift.

If we change the (still equal) input voltages by a large amount, then the circuit will cease to function as just described. For example, if we take the input voltages down to near the $-V_{EE}$ rail then the current source may no longer function properly. This would determine the amplifier's common-mode input range.

The high sensitivity of the transistor's collector and emitter currents to base voltage comes into play when we make the voltages at the two inputs slightly different. This breaks the symmetry and causes a larger proportion of `IE` to flow in one transistor than in another. For example, if we increase `VB1` slightly and decrease `VB2` by the same amount then a greater proportion of `IE` will flow in Q1 than Q2. This will cause the voltage drop across R1 to be larger than that across R2, so `VC1` will be lower than `VC2`. In op amp terminology, if we take a single-ended output from C2 then `VB2` will act as the inverting input and `VB1` as the non-inverting input.

DC Sweep

It is useful to look at the relationship between the input voltage difference (`VB2` – `VB1`) and voltages at the two collectors over a range of DC values for the input. We can plot this using a DC sweep simulation in LTspice. To do this, select the DC sweep simulation command, select the source as `V1`, set sweep type to linear and select the range (start and stop voltages) and the increment value. The simulator will calculate DC voltages in the circuit for all values of the selected source starting at the start

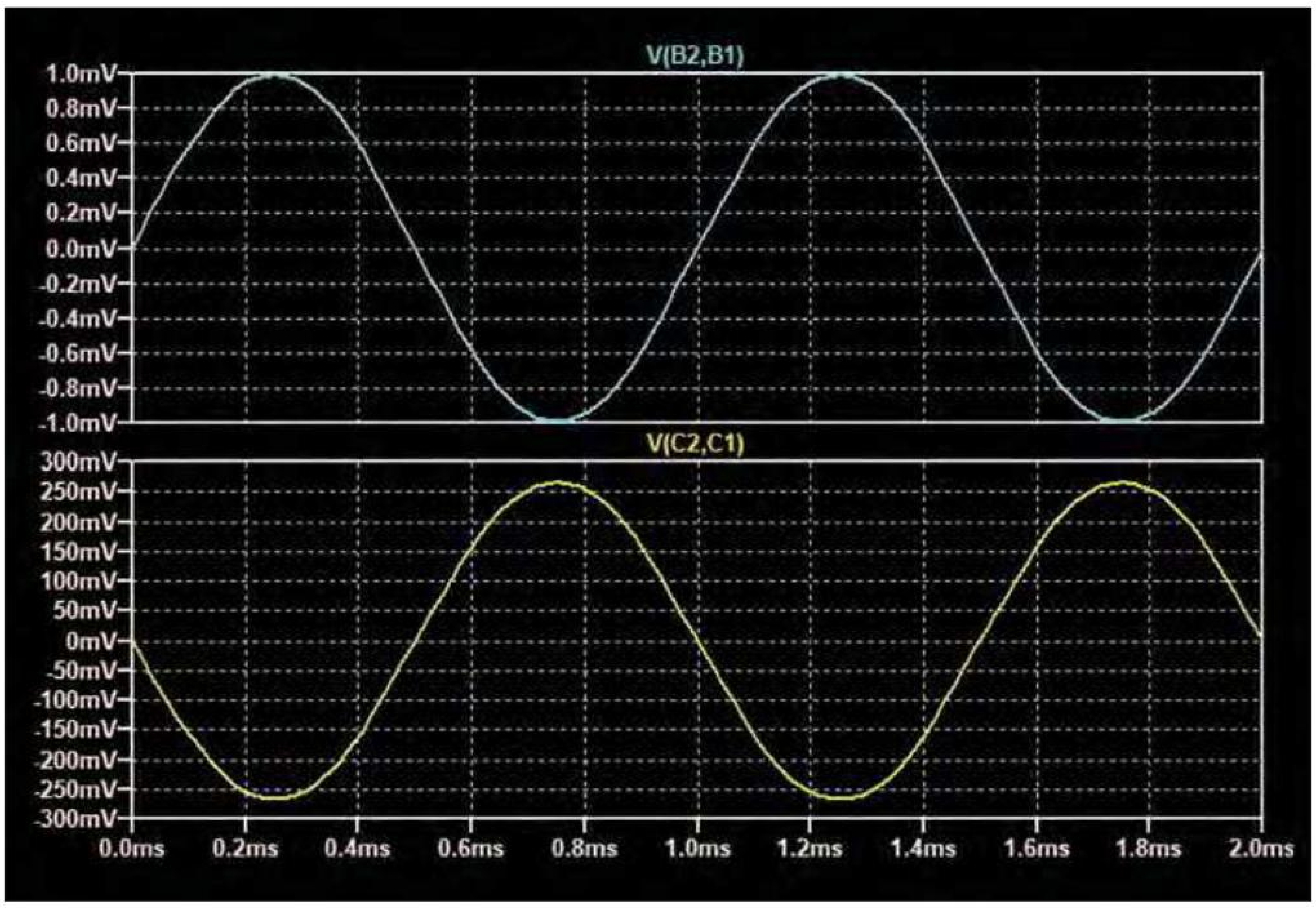


Fig.6. Plot of differential input voltage (VB2 – VB1) and differential output voltage (VC2 – VC1) for the circuit in Fig.4.

voltage, stepping by the increment until the stop voltage is reached. Stepping `V1` by 1mV from –150mV to +150mV and plotting the voltages at C1 and C2 produces the result shown in Fig.5.

Fig.5 shows that differences over a few tens of mV result in most of `IE` flowing in one or other of the two transistors. Over a large input difference range the response of the circuit is exponential, but in the range of a few mV difference between the inputs the change in the output voltage is near-enough directly proportional to the input difference (the central part of the curves in Fig.5 are straight). So, we have a linear differential amplifier for small input voltage differences.

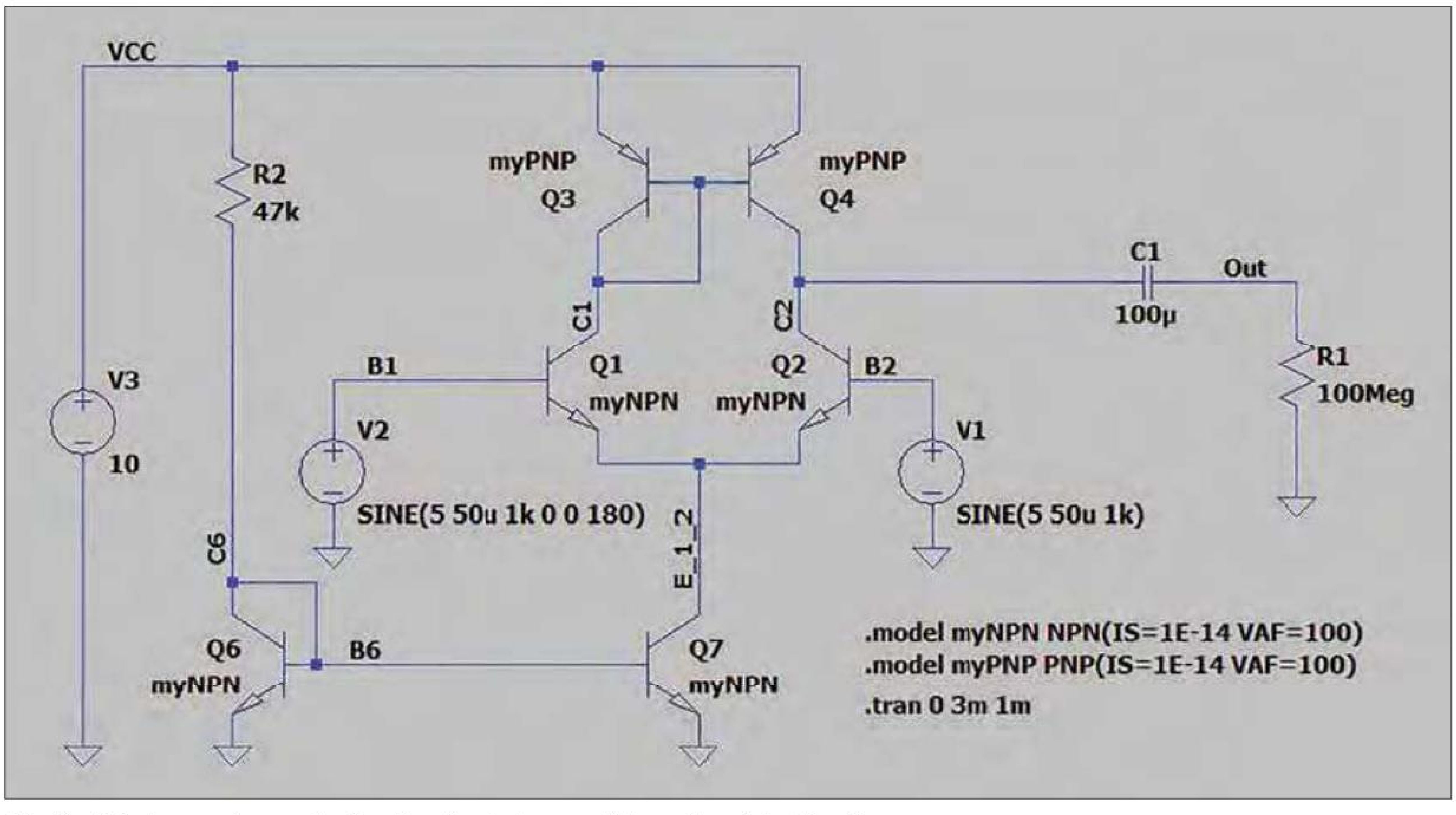
The voltage gain of the circuit in Fig.4 (difference-in to difference-out) is given by $g_m R_C$ where R_C is the collector resistor value (equal to both R1 and R2). g_m is the transconductance gain of the transistor – the ratio of collector signal current (output) to base-emitter signal voltage (input). People are generally more familiar with β (or h_{fe}) as the transistor gain – this is the current gain, but using transconductance is often more convenient when we are dealing with a voltage input.

We often assume that β is fixed at 100 if we do not have more specific information, and indeed the default transistor model in LTspice uses this value. g_m is more complex in that it varies with bias current, so we can't assume a fixed value. Specifically, $g_m = I_{CQ}/V_T$ where I_{CQ} is the bias or quiescent collector current and V_T is the 'thermal voltage', a term which occurs in many semiconductor equations. V_T varies with temperature but is about 26mV at 27°C – a commonly used default value in rough calculations (27°C is also LTspice's default temperature). For the circuit in Fig.4, I_C is $I_E/2$ = 0.5mA, so g_m = 0.0005/0.026 = 19.2mS (g_m is current/voltage which is 1/resistance, which is measured in siemens, symbol S). The gain is therefore 0.0192 × 15,000 = 288. Knowledge of the expected gain and the linear input range indicated by Fig.5 informs the choice of input signal amplitude for a transient simulation. 1mV is used in Fig.4. The result is shown in Fig.6 – the output amplitude is 270mV, so the gain (270) is close to our rough calculation. Fig.6 shows a plot of voltage differences – note the syntax for the waveform `V(X,Y)` is the voltage at `X` measured from `Y`. Such plots can be obtained by right-clicking on wire `X` and selecting 'Mark Reference' from the menu, then clicking on `Y`.

The g_m equation shows that the choice of bias current from the current source influences the gain of the circuit. Running the circuit at a higher bias current provides more gain but has other effects too. Power consumption will be higher at higher bias currents and a transistor's base-emitter resistance is dependent on bias current. Increasing operating currents result in a proportional decrease in base-emitter resistance and hence reduced differential input resistance. This will need to be considered in a real design but will not affect the simulations discussed here as the inputs are driven by ideal voltage sources.

Active load

The gain of the circuit in Fig.4 can be increased by increasing the collector resistors as well as increasing the bias current; however, this also has its limiting factors. The output voltage with no signal present is $V_{CC} - R_C I_E/2$, the supply minus the voltage dropped by the resistor with the bias current flowing through it. Increasing R_C reduces this voltage, but it cannot go much below 0V or Q1 and Q2 will start to saturate (the emitters are at $-V_{BE}$). This limits the maximum R_C at a given bias current. Increasing V_{CC} could compensate, but this is likely to be constrained by the requirements of other



```
.model myNPN NPN(IS=1E-14 VAF=100)
.model myPNP PNP(IS=1E-14 VAF=100)
.tran 0 3m 1m
```

Fig.7. LTspice schematic for the first stage of the circuit in Fig.1.

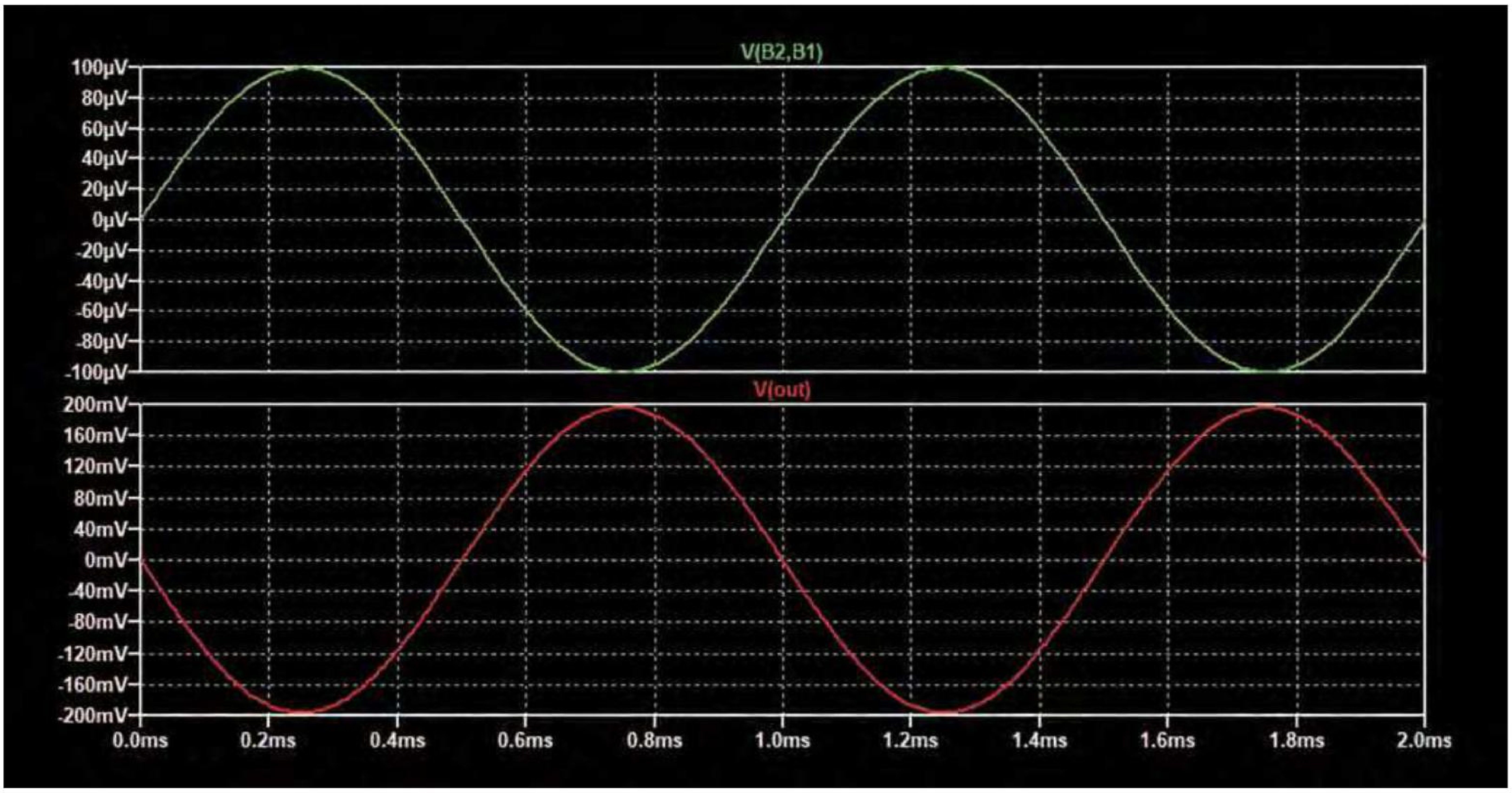


Fig.8. Plot of differential input voltage (VB2 – VB1) and output voltage (Vout) for the circuit in Fig.7.

circuitry, and realistically cannot be very large. The solution is to use an active load, as in the circuit in Fig.1, which has Q3 and Q4 in place of the collector resistors. Active loads allow bias currents to be set to any reasonable level while presenting an effective resistance value equal to the transistor's output resistance, which can be as high as megaohms.

Q3 and Q4 in Fig.1 form a current mirror like that in Fig.3, except using PNP transistors. Recall the discussion on the symmetry of the differential amplifier. If we assume that the current mirror is ideal, then with no differential signal present (equal base voltages for Q1 and Q2) the circuit's balance is preserved. Q1's and Q2's collector currents are both $I_E/2$. Q1's collector current acts as the reference for the mirror and is copied from Q3 to Q4 where it exactly matches Q2's collector current. However, if we apply a voltage difference, then Q1's current copied to Q4 will not match the current in Q2. We cannot have two different currents in the same wire, so what happens? The answer is that the transistors are not perfect current sources and have some resistance between collector and emitter, referred to as their output resistance (r_o). The difference between Q4's and Q2's collector currents will flow in their output resistances. The resistances of the two transistors are in parallel as far as this difference current is concerned, so the effective value is the parallel combination of Q2's and Q4's output resistance, which is $r_o/2$, assuming they are matched.

Comparing this with the gain formula for the circuit in Fig.1 indicates a possible gain of $g_m r_o/2$ but the current delivered to the output is twice that of the circuit in Fig.4 because the current from Q1 is mirrored to the output (at C2), doubling the potential differential gain to $g_m r_o$. However, although the differential amplifier with active load is symmetrical in current terms, the diode-connected transistor Q3 presents a low resistance, so the voltage signal at C1 in Fig.1 is small. Therefore, we use the single-ended output from C2, which provides half the gain compared to differential output (if it were available), so the gain is $g_m r_o/2$.

Early voltage

The value of a transistor's output resistance depends on a parameter called the Early voltage (V_A); specifically, $r_o = V_A/I_{CQ}$ where I_{CQ} is the collector bias current. This is like the g_m and base-emitter resistance discussed earlier in being dependent on bias current. The default value for V_A in calculations is typically 100V, but for the default transistor models in LTspice it is infinite, so simulation results will not match expectations unless this is changed. Therefore, the Early voltage (`VAF` parameter) has been set to 100 in the simulations used here. The value of r_o for the circuit in Fig.4 is 100/0.0005 = 200kΩ, which does not have much effect in parallel with R_C of 15kΩ, but including it gives the gain as 268, which is closer to the simulation.

Finally, we get to the simulation of the input stage of Fig.1. The LTspice schematic is shown in Fig.7. Here we have somewhat arbitrarily chosen a current of 200µA for the mirror reference (100µA bias each for Q1 and Q2), R2 is set using $(V_{CC} - V_{BE})/I_{ref} = (10 - 0.6)/200\mu A = 47k\Omega$. With this bias current we get $g_m = 100\mu A/0.026 = 3.85mS$ and $r_o = 100/100\mu A = 1M\Omega$, so the gain is $1M\Omega \times 3.85mS/2 = 1923$. Simulation results are shown in Fig.8. The simulated gain is about 1970.

The gain of the circuit in Fig.7 is strongly dependent on the load resistance – driving a low resistance will dramatically reduce the gain. This is why an extremely high load resistance was used here. The output resistance is around 500kΩ, so setting R1 to this value will half the output voltage. The second stage in Fig.1 presents quite a low resistance load to the differential amplifier, so the gain from the input to Q2's collector in circuit in Fig.1 will be much lower than the circuit in Fig.7. However, the second stage can add significant gain, so overall the circuit can have a higher gain than with just the single stage. Despite this, it can be argued that the circuit in Fig.1 wastes much of the potential gain from the differential amplifier, and many op amp designs use circuits with a much higher input resistance for the circuit directly after the differential stage.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*. The examples and files are available for download from the *PE* website.

Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 20: Ultrasonic obstacle avoidance

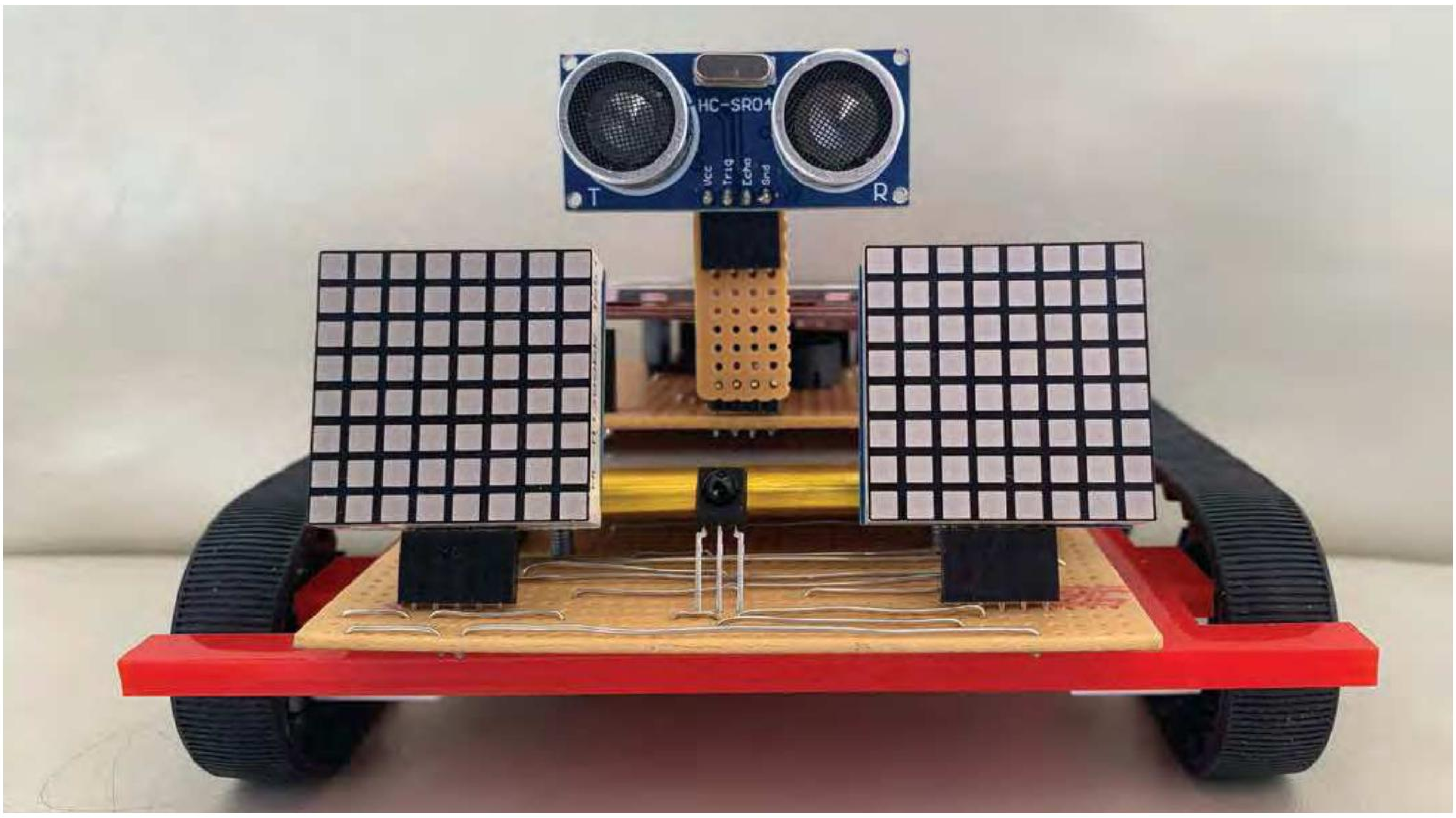


Fig.39. By adding an ultrasonic distance module, the *MRB* can be programmed to avoid crashing into objects.

We now come to the last part of our *Micromite Robot Buggy* (*MRB*) mini series. The objective this month is to enable it to roam autonomously without crashing into anything, which means it will need to have some form of obstacle avoidance mechanism. So, this month we are going to show you how to implement this feature by using a low-cost ultrasonic distance sensor mounted on the front of the *MRB* (see Fig.39). This will require us to make a simple hardware modification to the TFT module that we originally assembled back in *Part 15*. For our *MRB* program code to interface with the ultrasonic distance sensor, we will use the Micromite `DISTANCE` command. As usual, MMBASIC greatly simplifies everything for us; in this case, the `DISTANCE` command communicates directly with the ultrasonic sensor, returning a numeric value that represents the distance (in centimetres (cm)) to an object positioned in front of it.

We will start this month by working through the hardware modification to the TFT module, and then we will test that it works correctly by writing a five-line demo program that incorporates the `DISTANCE` command. This demo program will perform the function of a basic, yet highly accurate *Digital Tape Measure* – a great little project in its own right. We will then take this demo program and modify it slightly so that it forms the basis of our *MRB* obstacle avoidance code.

Concept of obstacle avoidance

The ultrasonic (US) distance sensor hardware, along with the MMBASIC `DISTANCE` software command, enables our program code to measure the distance (in cm) to any object that is in front of the *MRB*. By continually measuring the distance value while the robot is moving forward, the *MRB* program code can be made to automatically 'apply the brakes' should the distance value fall below a certain threshold value.

Micromite code

The code in this article is available for download from the *PE* website.

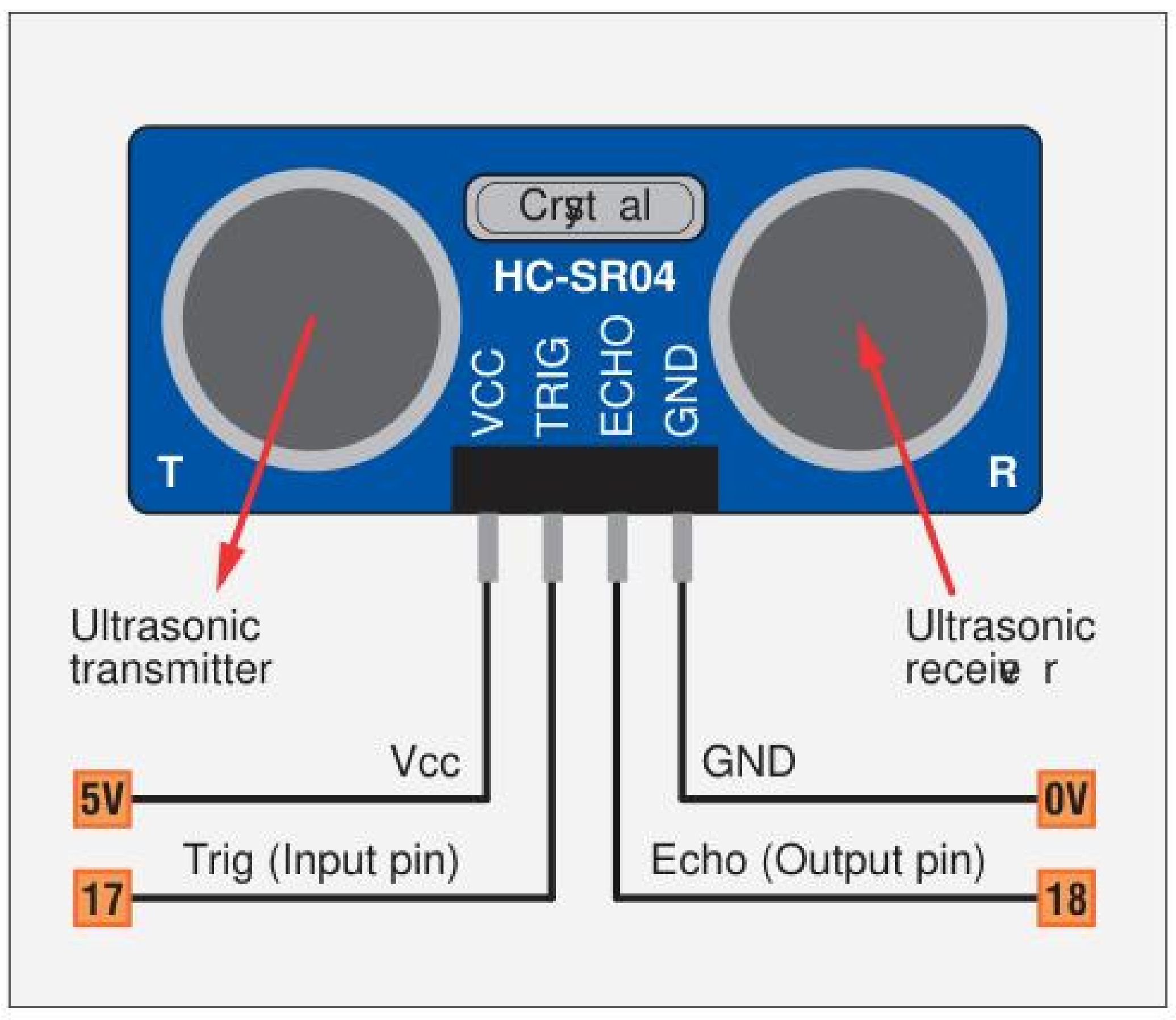


Fig.40. The low-cost Ultrasonic distance module used in the MRB has just four pins. Two pins supply 5V power, and the other two pins connect directly to Micromite I/O pins.

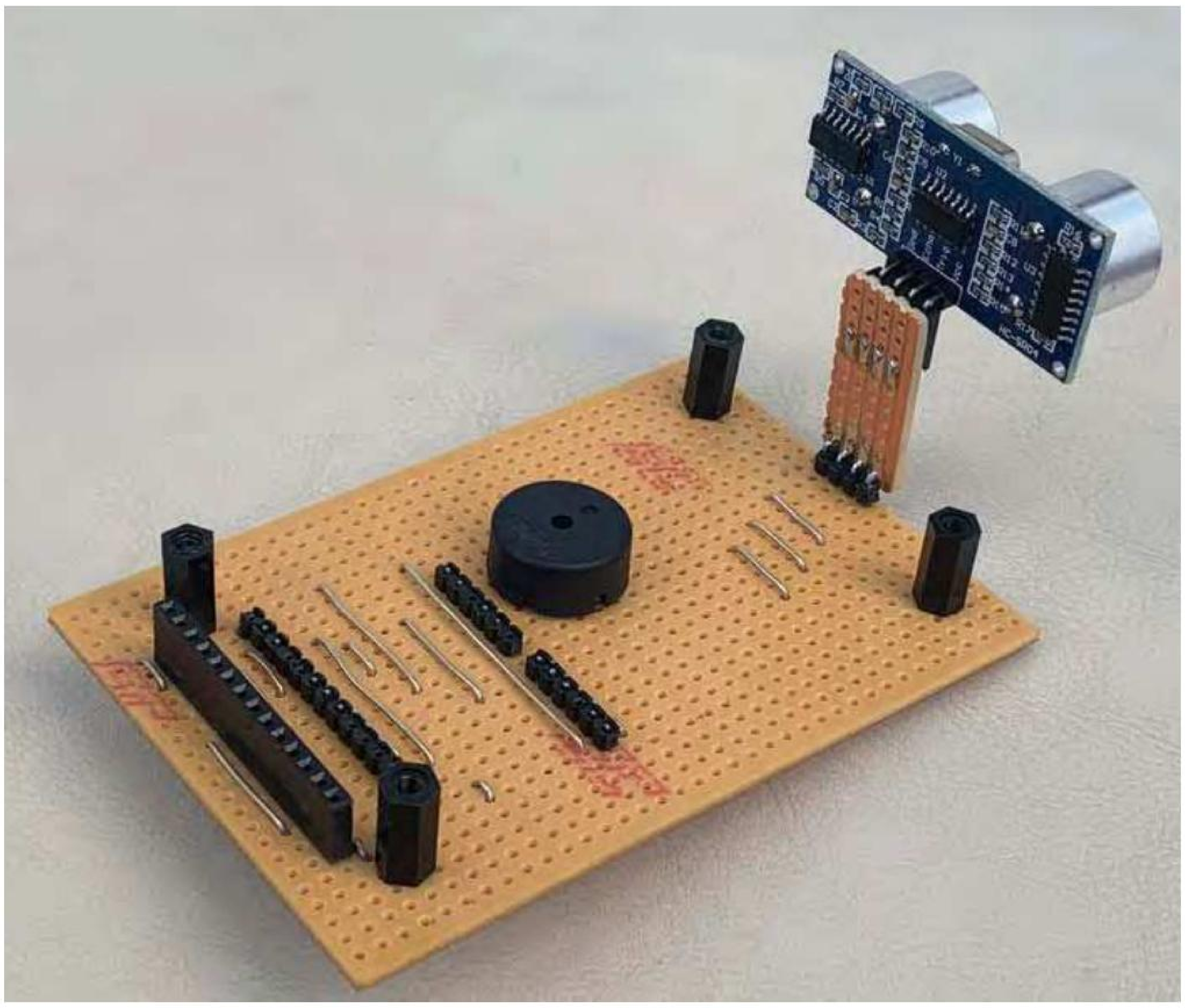
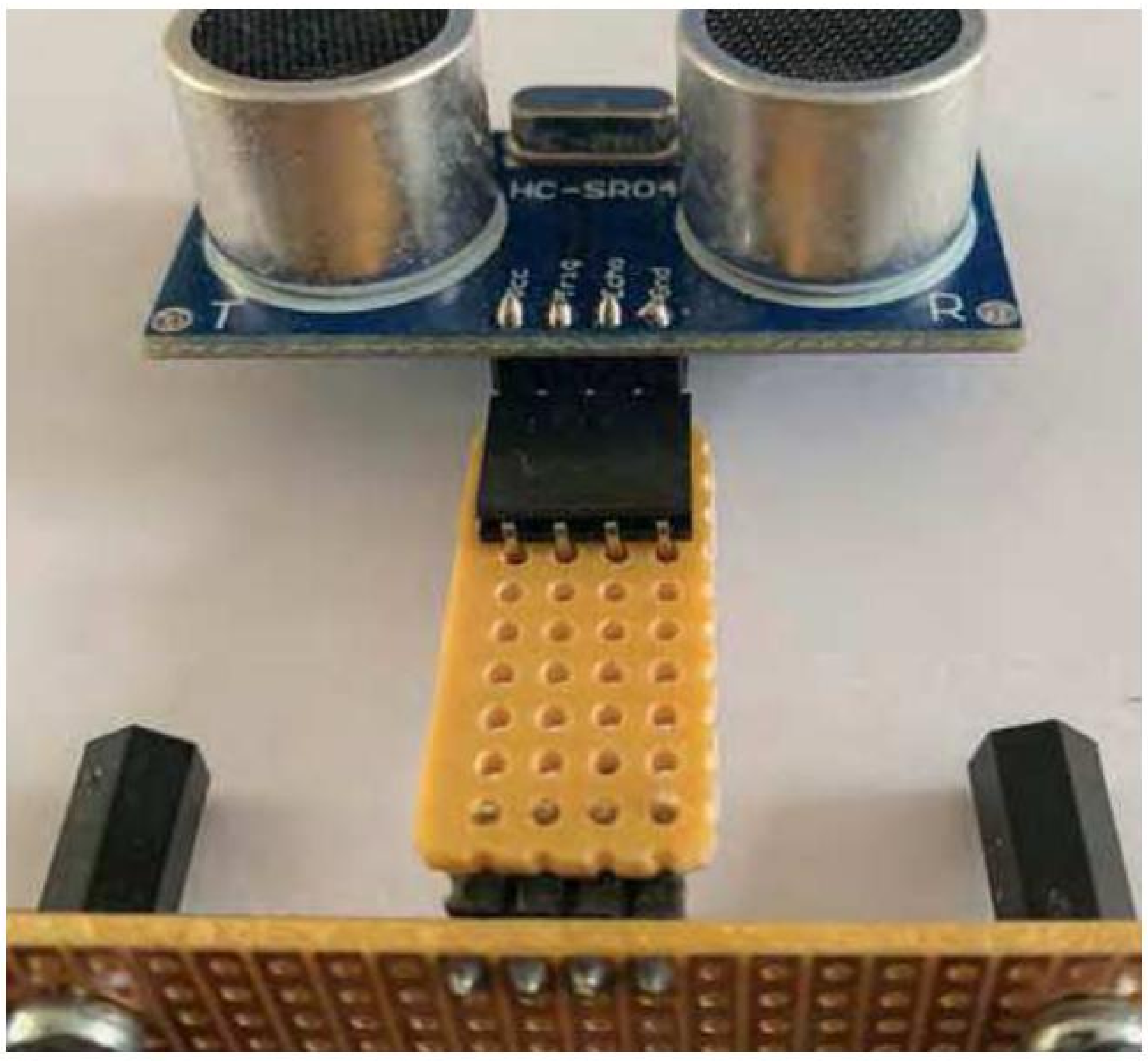
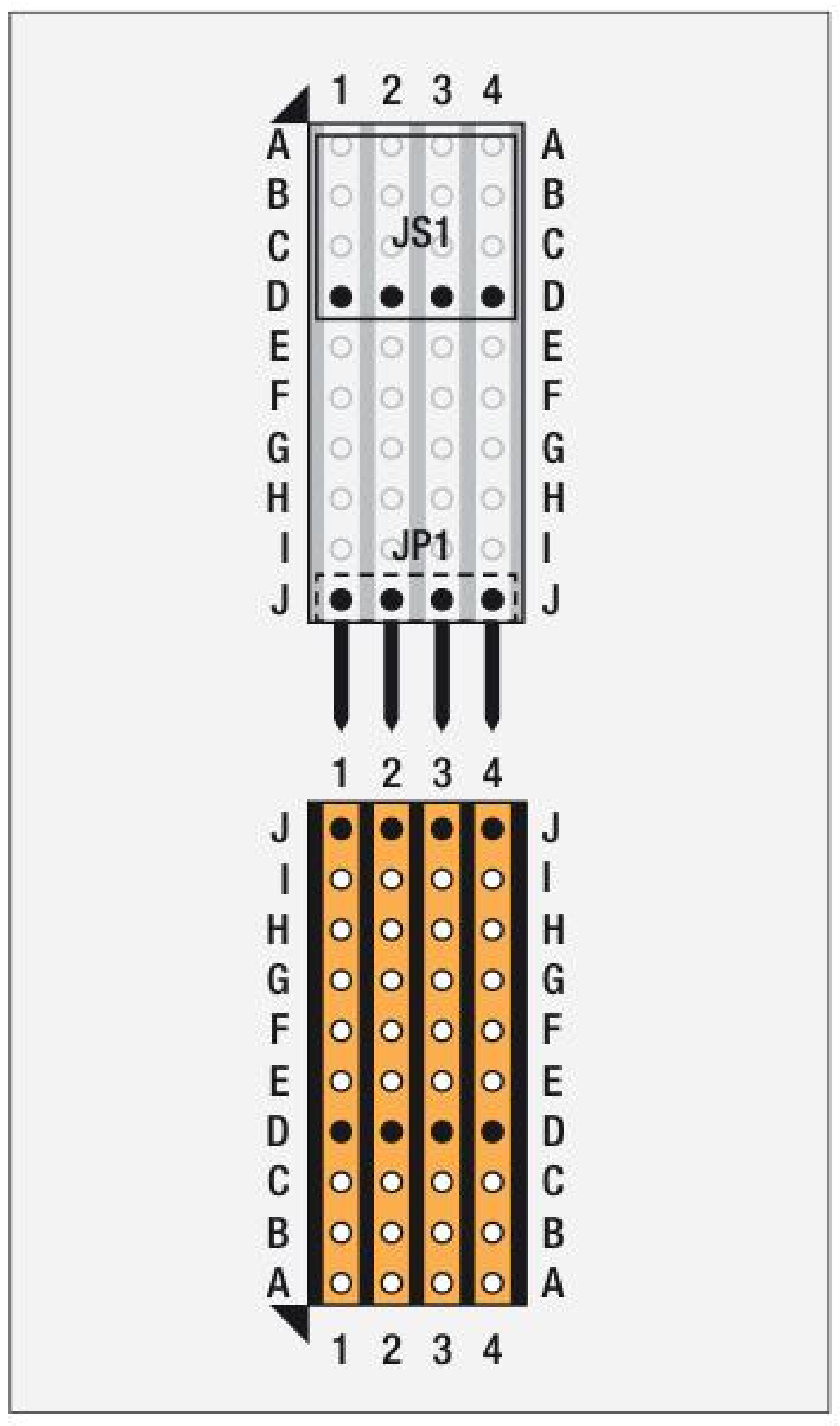


Fig.41. A small piece of stripboard acts as a mini-riser board. This allows the US module to have an unobstructed view over the animated LED eyes.





For example, consider setting a threshold value in the *MRB* code to 10cm. Whenever the distance measured is greater than this 10cm threshold, then the *MRB* can be allowed to continue to move forward without the risk of hitting anything. However, as soon as the measured distance falls below the 10cm threshold, then the program code can be written to automatically stop the *MRB* from moving forward, and hence prevent it from crashing into an object.

This distance-measuring method of obstacle avoidance is much better than implementing some fancy form of front-mounted mechanical 'bumper-switch' (as used in some other mobile robots). Implementing the bumper-switch method means that the robot has to actually crash into an object first in order to apply the brakes. For this reason, we consider the bumper-switch method as *collision detection* rather than *obstacle avoidance*.

The HC-SR04 module

The US distance sensor module that we are using here is the readily available HC-SR04. It comprises a US transmitter, and a US receiver, along with just a few support components. It has four pins presented on a 0.1-inch header (see Fig.40). Two pins supply the required 5V power, and there are two control pins. The control pin marked 'TRIG' is an input trigger, and the 'ECHO' control pin is an output. The module operates as follows: when a pulse is sent to the TRIG input pin from an external device (in this case from the Micromite) the US transmitter sends out a short pulse of US waves. The US receiver then waits for a short period of time to see if it can detect these US waves being reflected (ie, bounced) off an object directly in front of it. If it sees a reflection, then the ECHO output pin sends out a pulse to an external device (the Micromite). The time between the transmission of the US wave and the reception of any reflected waves (the time between sending a TRIG pulse and receiving the ECHO pulse) will infer the distance to the object – much like the way radar operates using electromagnetic waves. The Micromite performs all of the timing calculations from within firmware (whenever the `DISTANCE` command is used) and conveniently returns a calculated distance as a numeric value – more on this later.

Circuit diagram

The circuit connections for adding obstacle avoidance to the *MRB* is also shown in Fig.40. As always, it is just a matter of connecting the external hardware (ie, the US distance sensor) to the relevant power pins and Micromite I/O pins. It really could not be any simpler as there are only four physical connections required. Out of the four connections, only two are required to be connected to I/O pins on the Micromite. Checking which Micromite pins are still available for use on the *MRB*, we only have pins 17 and 18 that are currently unassigned to anything – therefore we will use these two I/O pins. Hence the four connections that need to be made are:

- Vcc connected to 5V (the 5V pin is physically to the right of Micromite pin 15)
- TRIG connected to Micromite pin 17
- ECHO connected to Micromite pin 18
- GND connected to 0V (which conveniently is on Micromite pin 19).

All four of the US distance sensor module pins can be brought together into a 4-way header on the TFT module; however, we will need to make a slight modification to the TFT stripboard first. We must also ensure that the US distance module is physically mounted in such a way that it can face forwards on our *MRB* without being impeded by the animated eyes (if installed). This we can do by adding a new mini-riser board (see Fig.41).

Modifications to the TFT module

The assembly of the TFT module was discussed in *Part 15* (*PE*, April 2020). Referring back to Fig.5 from that article, you can see that the Micromite pins that are required for the US module (pins 17, 18, and 19) were not included in the header (J2) that ultimately plugs into the *MKC*. Therefore, the main modification to the TFT module requires the addition of these three downward-facing pins into J2. The stripboard layout from *Part 15* is recreated here in Fig.42, and it has been updated to show the required US modifications in red. As can be seen, in addition to the three pins for J2, there are seven track cuts, four wire links to insert, and also the soldering of a new mini-riser board via a 4-way right-angle header pin (see Fig.41).

Begin by making the seven track cuts on the *MRB* TFT module; ensure you follow the usual practice of marking out first, then checking the positions at least twice. Once the cuts are made, do a quick visual check to ensure that no copper swarf is bridging across neighbouring tracks.

Next, insert the three downward-facing pins into the plastic housing of J2 into positions V15, V16 and V17. These three new pins will ultimately be inserted into the *MRB* daughterboard, so do check that their length matches the existing downward-facing pins that are on the TFT module.

Next, install the four jumper links, as shown in Fig.42; again, make sure you check for and remove any accidental solder bridges with neighbouring tracks.

Mini-riser board

The mini-riser board is built from a small piece of stripboard 4-tracks wide, by 10-holes long (high), as shown in Fig.41. To this we need to solder a 4-way socket (that the US distance module plugs into), and a 4-way right-angle pin header (to solder the mini-riser board directly to the TFT module). Note that there are no track cuts or wire links needed on the mini-riser board.

Begin by cutting out the required size stripboard and solder the 4-way socket and the 4-way right-angle connector as shown in the various photos in Fig.41. Perform a visual check and ensure you remove any solder bridges between neighbouring tracks. Last, carefully solder the mini-riser board to the TFT module into positions A11-A14 (highlighted in red in Fig.42).

It is now time to mount the modified TFT module (complete with the new mini-riser board) onto the *MRB* daughterboard. Insert the US distance sensor into the 4-way socket, ensuring the US transmitter and receiver units are facing forwards. Plug in all relevant modules so that the *MRB* can be powered up as usual. We will now load a simple test program to check that the US distance sensor is working correctly.

Testing the US distance sensor

Begin by downloading the file **MRB_DigitalTapeMeasure.txt**, and then install it onto your *MRB* in the usual manner. On running the program, you should see the TFT screen clear to a blue screen with a thin green border. In the centre of the screen there should be a number (displayed in white). This number represents the distance being measured by the US sensor.

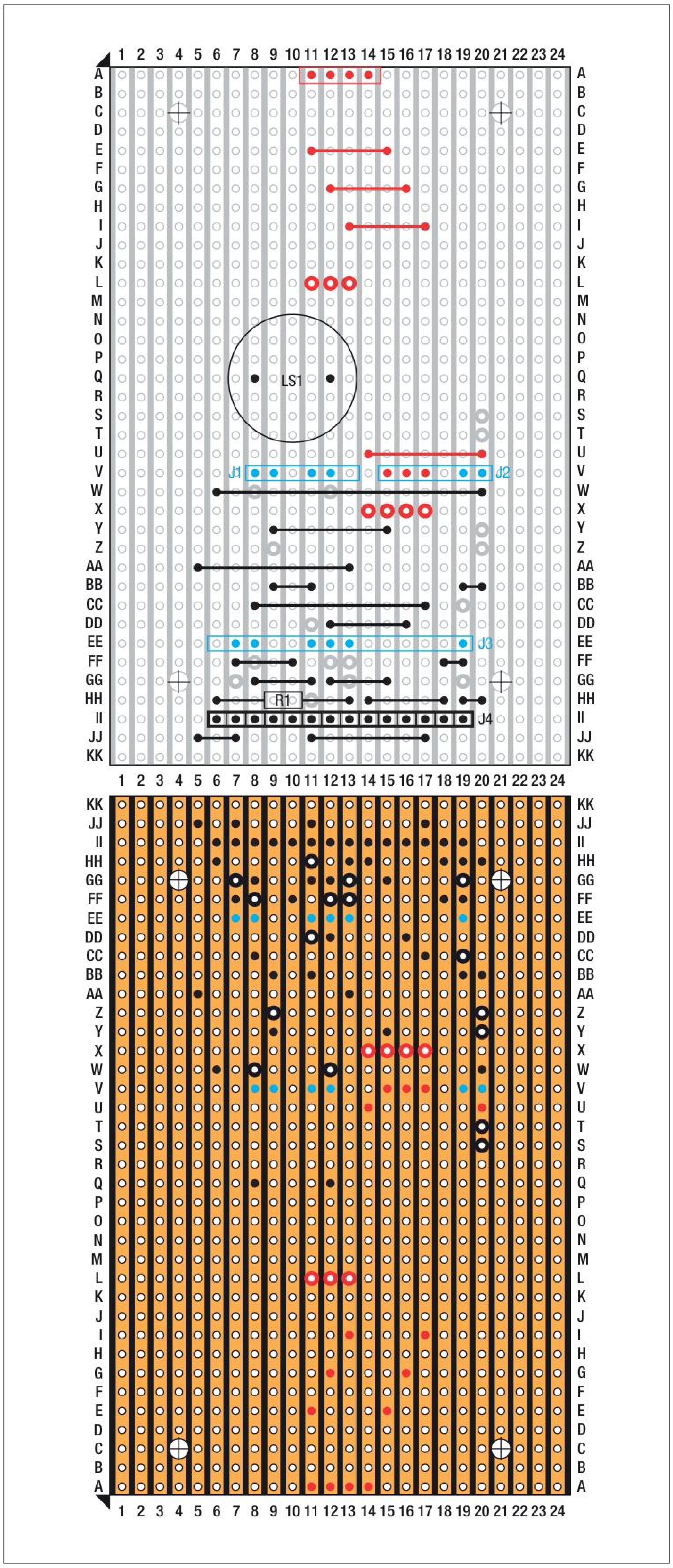

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA BB CC DD EE FF GG HH II JJ KK
LS1
J1
J2
J3
J4
R1

Fig.42. The original *MRB* TFT module from Part 15. The required US modifications are highlighted in red.

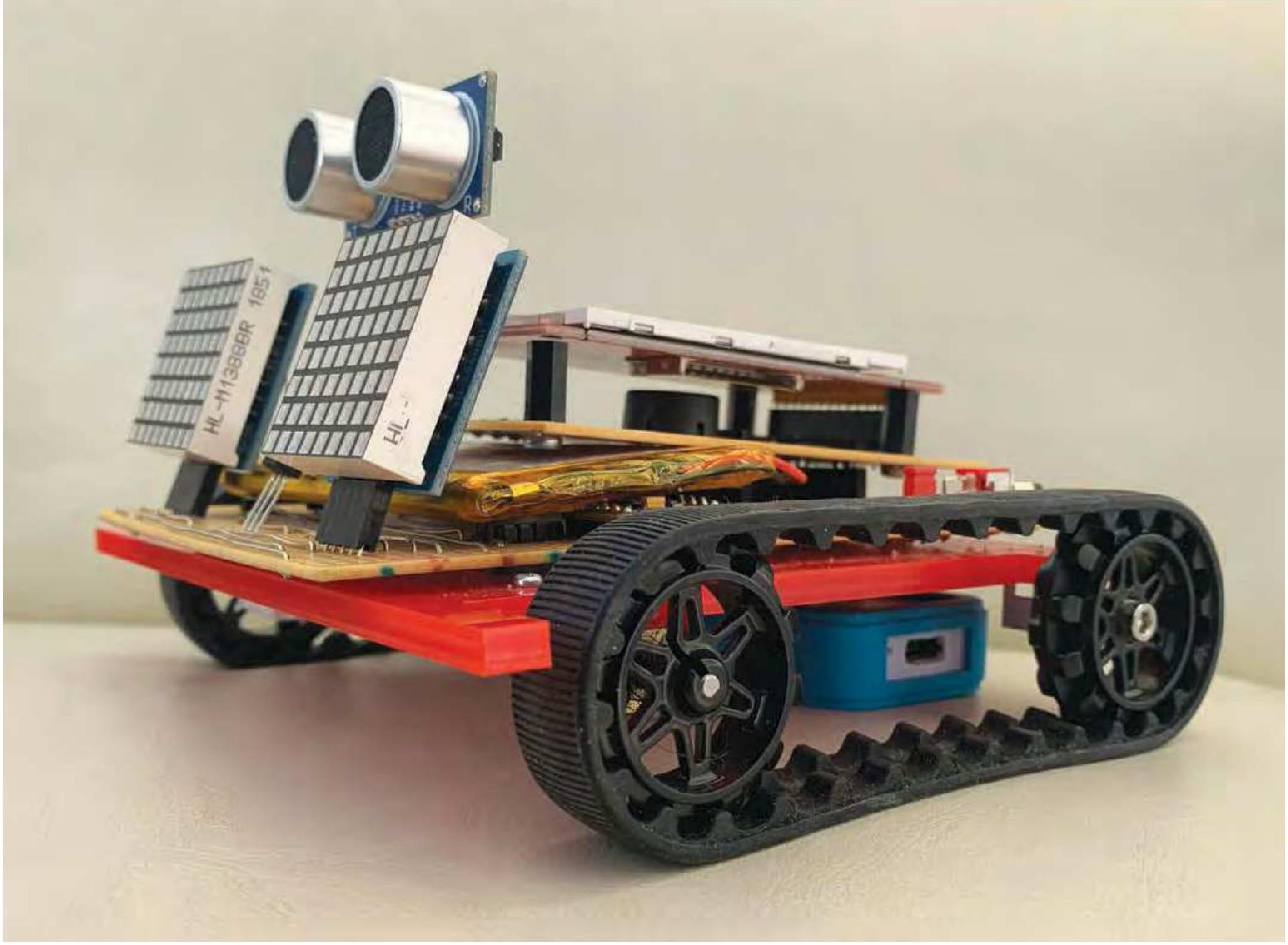


Fig.43. Side view of the completed *Micromite Robot Buggy.*

If the number displayed is –2, then the Micromite is not seeing the US sensor correctly. If this happens, first check the US sensor is inserted correctly into the 4-way socket. If this is fine, then you will need to carefully check that all modifications made to the TFT module match Fig.42.

Once you observe a number on the screen other than –2, then position your hand in front of the US module so that the US waves can bounce off it (or use a book). Now move your hand back and forth in front of the US sensor and you should see that the number displayed on the TFT changes – increasing in value as you move your hand away from the sensor, and reducing in value as you move your hand towards the sensor. If this appears to work, then point your robot towards a nearby wall and you should see the number remain reasonably static. Now use a tape measure to measure the actual distance between the US sensor and the wall – you should find the displayed number on the TFT is within a couple of centimetres of what you measured. If not, then you may need to slightly alter the angle of the US sensor so that it is pointing at right-angles to the wall.

If all is working as described above, point the *MRB* towards various other flat objects and check the accuracy of the distance shown on the TFT. Note that any object made from a soft material (such as a cushion or an item of clothing) may not be able to reflect the US waves and hence will not be detected; therefore, ensure you use relatively solid objects for this test, and you should find that your *MRB* is now operating as an accurate digital tape measure.

The `DISTANCE` command

Press `Ctrl_C` to stop the program running, and type `EDIT` so that you can take a look at the code. The Main Program comprises of just five lines of code, as follows:

```
DO
  d=DISTANCE(17,18)
  TEXT ………,…STR$(INT(d))…, ……
  PAUSE 100
LOOP
```

As you saw when you ran the **DigitalTapeMeasure** program, the above code continually displays the measured distance on the TFT screen. The code is just a simple `DO…LOOP` with the magic happening in the line: `d=DISTANCE(17,18)`. The format of the `DISTANCE` command requires two values to be passed – these are the pin numbers that connect to the TRIG pin and the ECHO pin respectively. The MMBASIC Firmware will then automatically send a pulse to the TRIG pin (output), and will wait for a reflection pulse on the ECHO pin (input). The time taken to see any reflected pulse is then converted into a numeric value that represents the true distance (in cm).

In the above code, this numeric value is loaded into variable `d`. Note that the `DISTANCE` command automatically configures the two Micromite pins to the relevant I/O state – in other words, there is no need to use the `SETPIN` command to configure pins 17 and 18.

The second line of code in the `DO…LOOP` uses the `TEXT`, `STR$(…)` and `INT` commands to display the integer value of `d` on the TFT (effectively the integer value drops any decimal places making an easier-to-read display).

Finally, the `PAUSE` command is included in the `DO…LOOP` to prevent the TRIG pulse from being generated too soon after the previous measurement was triggered.

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Scrolling further down the code into the subroutines section, you will see that there are quite a few lines of code, each containing many numbers. These numbers are part of what is known as a 'CFunction'. This topic is well beyond the scope of this series; however, in essence, they contain the code that adds the `DISTANCE` command into MMBASIC. For more information, refer to the **Distance.pdf** file (available for download from the September 2020 page of the *PE* website)

So, in summary, to measure the distance of an object from the sensor, and to then load the result into a variable, you simply use the command syntax:

```
variable = DISTANCE(TRIG_pin_
number, ECHO_pin_number)
```

Adding obstacle avoidance to the MRB

We will now modify the code from last month (**MRB_IR_Control.txt**) to include obstacle avoidance. Currently, if you run the **MRB_IR_Control** program and press the blue arrow button on the 44-button IR transmitter, then the *MRB* will move forward at the set speed. The *MRB* will continue moving forward until you either:

- Stop it
- Select turn (to the left or right)
- Or the *MRB* hits an object (in which case there is a chance the motors can be damaged by being put under too much stress).

Now download **MRB_IR_Control_with_ObstaceAvoidance.txt** (available from the September 2020 page of the *PE* website) and install it on your *MRB*. `RUN` the program and point your *MRB* towards a wall. Then press the 'Forwards' button on your IR remote and observe what happens. If all is well, your *MRB* will automatically stop short of the wall with a notification on the TFT screen, as well as an animated eye effect being displayed. However, you may feel more comfortable to be on standby just in case it does not stop!

This version of the program simply monitors the measured US distance whenever the *MRB* is moving forward. If this value is below a threshold distance, the *MRB* is made to stop (as discussed at the start of this article). As well as stopping the motors, we also call an animated eye-effect subroutine, as well as displaying a warning message on the TFT screen.

As usual, the Micromite's program code is commented throughout, so do take a look and have a go at altering the stopping distance (and see how close you can get it to stop in front of objects before there is a collision).

The code to do all of the above-mentioned features should be reasonably familiar to you by now, but if not, then please read the comments included in the code to help you understand how it all works.

Allowing the MRB to explore by itself

Finally, this month we will run one more program that you should then use as a basis to write your own robot code. Download **MRB_Self_Explore.txt** from the September 2020 page of the *PE* website and install it on your *MRB*. This program will allow your *MRB* to roam freely without crashing into large objects. The IR transmitter is used only for two things: to start exploring (press the blue forward arrow button) and for the emergency stop (press any other button on the IR transmitter).

`RUN` the program and press the blue forward arrow button. This will make your *MRB* move and it will appear to go off and roam around by itself. Any time you feel it necessary to apply the emergency brakes, simply press any other button on the IR remote – this may be necessary if the *MRB* has run into a small undetected object.

The point of this program is really for it to be the basis for you to create your own *MRB* functionality. By now you know how to write code to:

- Move the *MRB*
- Avoid the *MRB* hitting objects
- Draw and animate the eye images
- Make beeping sounds (and play simple tunes)
- Write to the colour TFT touch screen
- Control via an IR remote control (or from your Terminal program via Bluetooth).

The design concept of the *MRB* was to bring together many of the topics that we covered in the *Make it with Micromite* series.

Do please have a go at writing your own *MRB* program code. Start simple, and continually add new features. Any time you feel you're struggling then simply drop me an email and I will gladly help you out.

Next month

That's enough *Robot Buggy* for now – but we may return to it. In the next issue we will move on to a brand new topic: Micromite UART communication. Until then, have fun, and please do stay safe!

Questions? Please email Phil at:
contactus@micromite.org

Max's Cool Beans

By Max the Magnificent

Flashing LEDs and drooling engineers – Part 7

Well hello there! How nice it is to see you again. It probably won't surprise you to hear that things have been progressing apace here at Maxfield Manor with regard to my 12 × 12 ping-pong ball array. I should perhaps warn you that we will be leaping from topic to topic with the agility of young mountain goats in this column, so please take a moment to make sure you're wearing appropriate clothing before we proceed further.

Blinded by the light

Let's commence by reminding ourselves that each of our pixels (ping-pong balls) contains a tricolour LED called a NeoPixel. Furthermore, each NeoPixel contains red, green, and blue sub-pixels, each of which can be driven with 256 different levels from 0 (0x00 in hexadecimal = 0% = fully off) to 255 (0xFF in hexadecimal = 100% = fully on).

I don't know about you, but whenever I'm working on a project like this, questions pop into my mind and I realise that there are all sorts of things I don't know. For example, suppose we were to light up one of our pixels 100% red. Now suppose we were to light up an adjacent pixel with 100% green and 100% blue, resulting in cyan. Does this mean that the cyan pixel is twice as bright as the red pixel? In turn, does this mean that we should really light the green and blue sub-pixels at 50% (128 in decimal = 0x80 in hexadecimal) so as to achieve the same brightness as the red pixel?

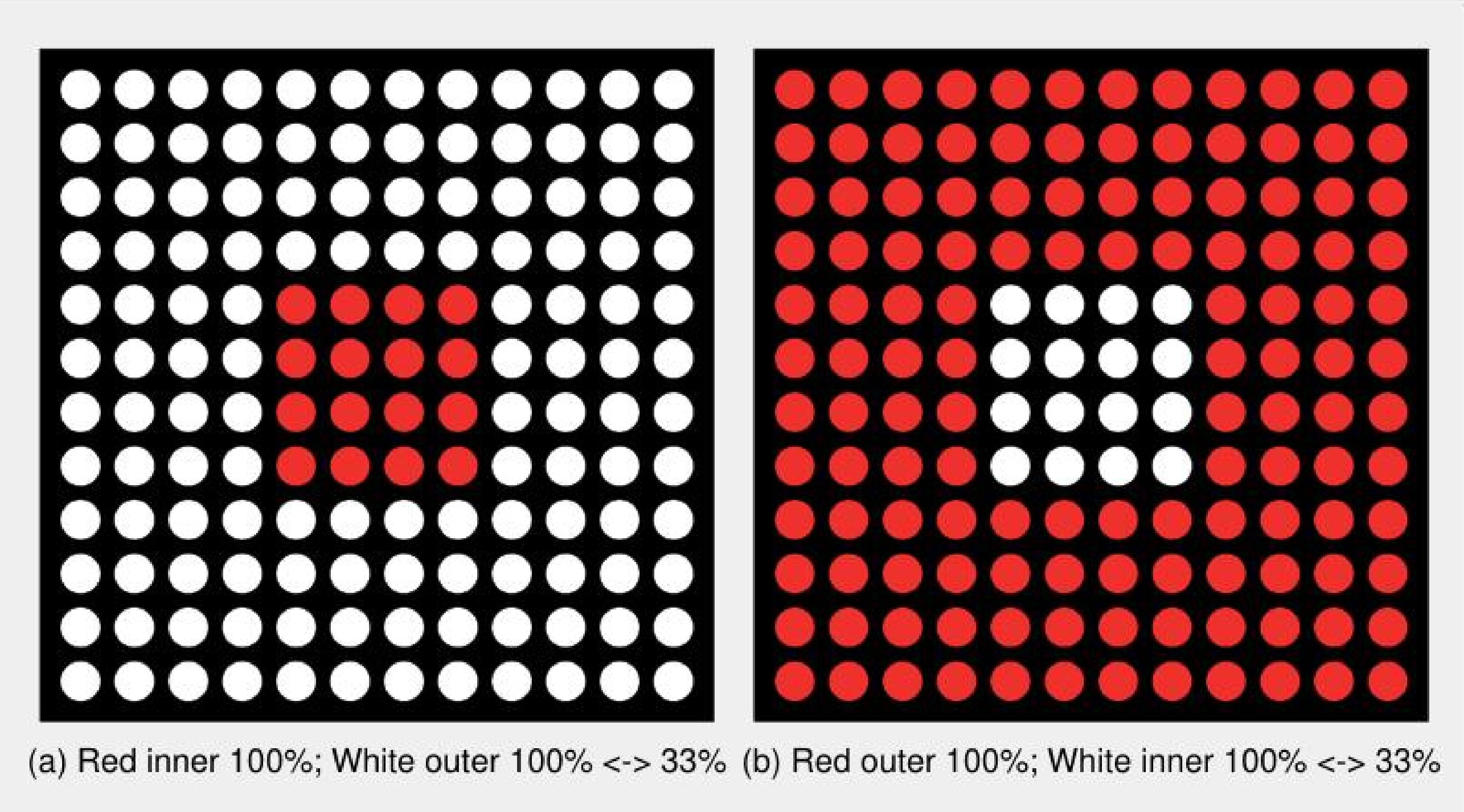
Similarly, if we were to take another pixel that's adjacent to our original red pixel and light all three sub-pixels to generate white, does this mean that we should really set the red, green, and blue sub-pixels to 33% (85 in decimal = 0x55 in hexadecimal) in order to achieve the same brightness as the red pixel?

I thought it might be a good idea to test things out. As you may recall from my previous column (*PE*, August 2020), our NeoPixels are connected together as a single string numbered from 1 to 144 (there's also a sacrificial pixel 0, which we're using as a voltage-level converter, but this plays no part in the visible portion of the display).

We're considering our array to be an (X,Y) matrix with both X (horizontal) and Y (vertical) positions numbered from 0 to 11, and with pixel (0,0) in the bottom left-hand corner. Also, we created a simple function called `GetNeoNum()`, which accepts X and Y values as arguments and returns the number of the corresponding NeoPixel in the string.

That's what I call a pixel array... and the shirt's not bad either!

As a first test of this brightness/contrast conundrum, I created a simple sketch (program) that fills the outer pixels with 100% white and an inner 4 × 4 square of pixels with 100% red (Fig.1a). Then we drop the surrounding white to 33%. Next, the sketch fills the outer pixels with 100% red and the inner square with 100% white (Fig.1b). Once again, we subsequently drop the white to 33%. We then cycle back to perform the whole sequence over and over again. If you wish, you can download this sketch and peruse and ponder it at your leisure (it's file **CB-Aug20-01.txt** – available for download, along with the other three files discussed in this column, on the September 2020 page of the *PE* website). For your delectation and delight, I've also created a short video showing all of this in action (**https://bit.ly/2OG9lgg**).



(a) Red inner 100%; White outer 100% <-> 33%
(b) Red outer 100%; White inner 100% <-> 33%

Fig.1. First contrast test.

As an aside, you may recall from an earlier column (*PE*, July 2020) that the creators of Adafruit's NeoPixel library provided two ways for us to specify the colour of a pixel. Let's suppose our string is called `Neos` and that we want to set the colour associated with pixel 42 to have red, green, and blue colour components of 128, 0, and 255, respectively (these would be 0x80, 0x00, and 0xFF in hexadecimal). If we wish, we can specify the colours individually using a statement like:

```
Neos.setPixelColor(42, 128, 0, 255)
```

Or:

```
Neos.setPixelColor(42, 0x80, 0x00, 0xFF)
```

As an alternative we can specify all three colours together as a single numerical value using a statement like:

```
Neos.setPixelColor(42, 8388863)
```

where the number is specified in decimal, or:

```
Neos.setPixelColor(42, 0x8000FF)
```

with the number specified in hexadecimal. Using a single numerical value in hexadecimal makes our lives a lot easier, so that's what we'll do. This explains why you will see the colour definitions in my sketches looking something like the following:

```
#define COLOR_WHITE 0xFFFFFFU
#define COLOR_BLACK 0x000000U
#define COLOR_RED   0xFF0000U
#define COLOR_GREEN 0x00FF00U
#define COLOR_BLUE  0x0000FFU
```

Note that adding 'U' (or 'u') characters on the end of these values informs the compiler to regard them as being unsigned (see this month's *Tips and Tricks* column for more discussions on the difference between signed and unsigned values). Most of the time this won't be necessary, but every now and then...

Next, I started to wonder if my 4 × 4 centre square was a tad small (16 pixels) in comparison to the surrounding area (128 pixels), so I decided to increase its size to 6 × 6. Fortunately, due to the way I created my original program, all I had to do to generate the new version was to change two definitions: `XY_CENTER_MIN` was changed from 4 to 3, while `XY_CENTER_MAX` was changed from 7 to 8. Once again, you can download this sketch (**CB-Aug20-02.txt**). And, once again, I've created a short video showing all of this in action (**https://bit.ly/2OG9lgg**).

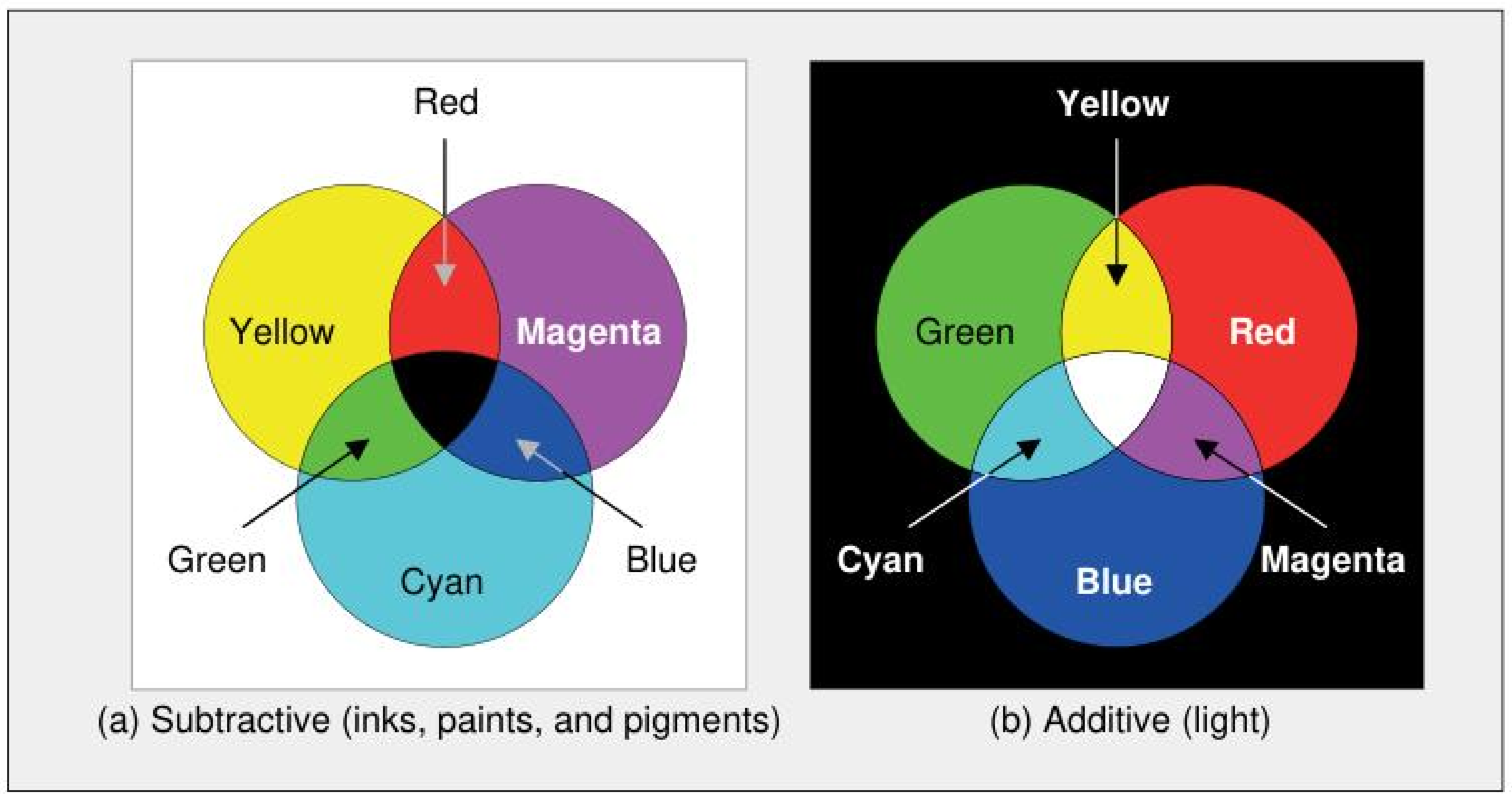
Personally, I think the 33% white looks a bit washed out. My conclusion is that, if we were trying to use our array to represent images or to play extremely low-resolution videos, then we would probably vary the intensity of each sub-pixel to balance everything out. By comparison, in the case of our simple effects, we probably want to make everything as bright as possible, which – happily – is my default position anyway.

Feeling random?

To give our effects an 'organic' feel, we're going to be using the C/C++ `random()` function, which accepts two arguments and returns a random result as follows:

```
result = random(min, max);
```

The `min` argument is optional. If this value is not specified, it will default to 0. This value is also *inclusive*, which means it may appear in the result. By comparison, the `max` argument is required and (for all sorts of reasons we won't go into here) it's also *exclusive*, which means it won't appear in the result. Another way to look at this is to observe that when this function is called it will return a result between `min` and `(max – 1)`.



(a) Subtractive (inks, paints, and pigments)
(b) Additive (light)

Fig.2. Subtractive and additive primary colours.

A bit of a drip

For our first series of effects, we're going to imagine that our array is lying flat on the floor and that occasional drips of water – virtual raindrops, if you will – are randomly falling from the sky. Whenever a virtual drip lands on one of our pixels (ping-pong balls), that pixel will light up bright white for a short period of time.

You may find it advantageous to download the sketch associated with this effect (file **CB-Aug20-03.txt**) and reference it in conjunction with these discussions.

As you will see, we declare two integer global variables called `OldX` and `OldY`, which we will use to keep track of the (X,Y) coordinates of the last pixel that was lit up. We initialise both of these variables with random values between 0 and 11 in our `setup()` function.

Most of this sketch is self-explanatory. The interesting part is where we generate the (X,Y) coordinates associated with a new drip as follows (the +1s associated with the maximum values are there to offset the fact that, as we just discussed, the `random()` function treats its maximum argument as being exclusive):

```
do
{
    newX = random(MIN_X, (MAX_X + 1));
    newY = random(MIN_Y, (MAX_Y + 1));
} while (condition);
```

This loop will be executed at least one time, and it will keep on executing until its `condition` is met (ie, returns `true`). But what condition should we use? One alternative would be to say:

```
((OldX == newX) && (OldY == newY))
```

In this case, the loop will keep on executing until the new pixel is different from the old pixel, but there's nothing to prevent the new pixel from being horizontally or vertically adjacent to the old pixel.

Personally, I prefer a tad more differentiation, so I opted to swap the `&&` (logical AND) operator for the `||` (logical OR) operator and use:

```
((OldX == newX) || (OldY == newY))
```

This means the new pixel cannot be on the same row or column as the old pixel.

The only other things to note about this sketch are that we also use the `random()` function to vary the duration of the flashes associated with each of the drips and the gaps between drips. Also, the last thing we do at the end of each cycle is set the values of `OldX` and `OldY` to be the values of `newX` and `newY`, respectively. This means that the pixel we just flashed will be considered to be our old pixel the next time we pass through the loop. Do you even need to ask?! Yes, of course I've carefully crafted a video showing all of this in action (see: **https://bit.ly/2OG9lgg**).

Do you believe in colour fairies?

When I was a little kid, I had a book that described how the red, yellow, and blue colour fairies spent the night repainting everything, which explained why all of the colours looked so bright and fresh each morning.

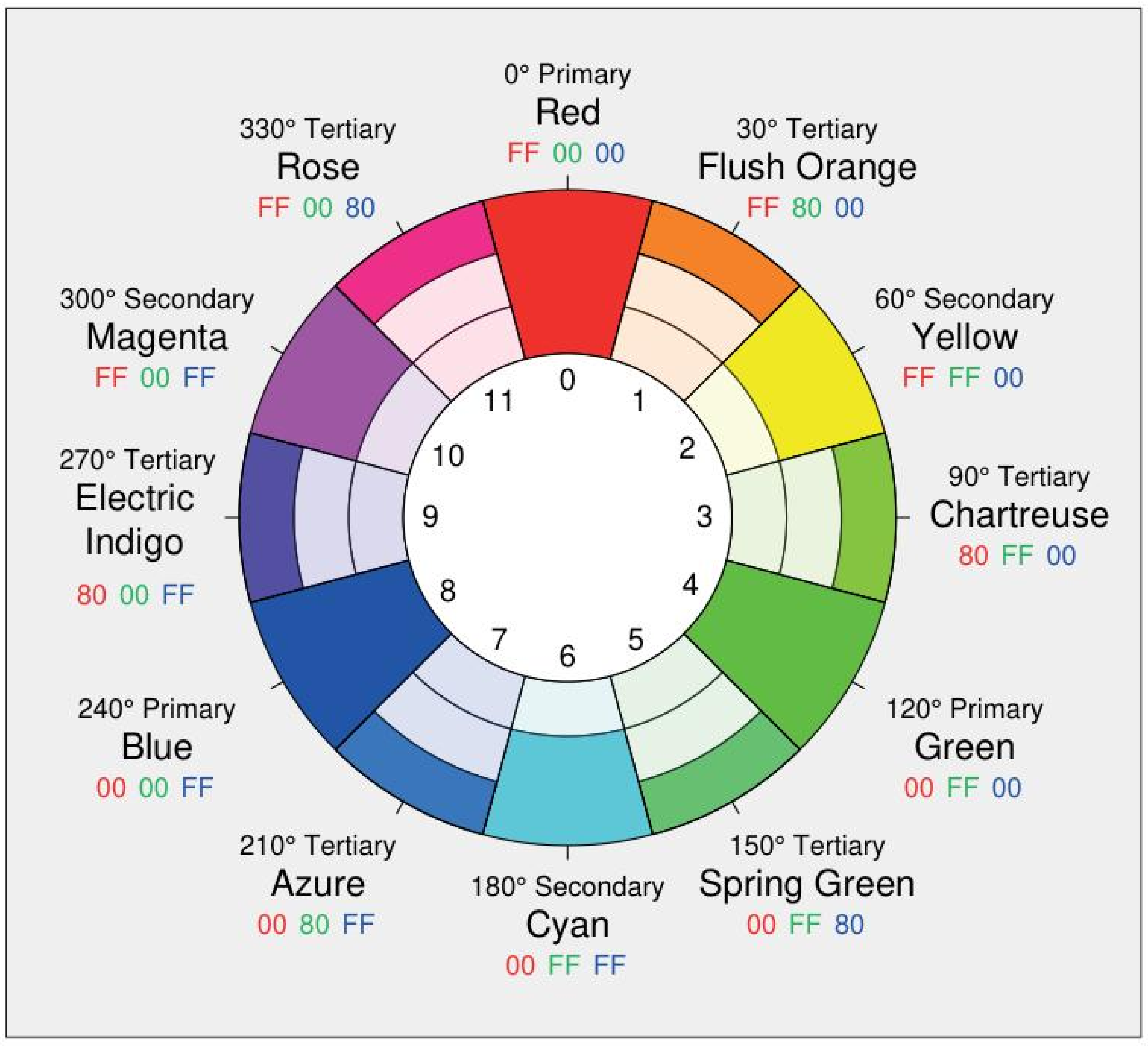


Fig.3. The colour wheel we will be using in our experiments.

This all made perfect sense to me, especially since I knew from school that the fairies could generate other colours by working together: red and yellow made orange, red and blue made purple, yellow and blue made green, and so forth.

Later, my teacher explained that red (R), yellow (Y), and blue (B) were primary colours. What she didn't say was that this was just one possible set of primaries, because the term 'primary colours' simply refers to a small collection of three or more colours that can be combined to form a range of additional hues, shades, tints and tones. For example, printers use cyan (C), magenta (M), and yellow (Y) inks as their primary colours. Furthermore, although it's possible to mix cyan, magenta, and yellow to form black, printers typically use a special black pigment. We use the letter K to represent this pigment because B could be confused with blue. This explains why we use the term CMYK when we're talking about printer ink.

Now, the thing about inks, paints and pigments is that they are subtractive in nature. One way to think about this is that we start with a white background illuminated with white light. The white background reflects all of the frequencies in the white light. When we start to add our colours, each colour absorbs (subtracts) some of the frequencies from the white light (Fig.2a). Furthermore, when inks, paints, or pigments are mixed together, they each absorb different frequencies. Basically, what we see is what's left over; that is, what isn't absorbed. When all of the colours are mixed together, they absorb all of the frequencies leaving us with nothing to see (ie, black).

By comparison, light is additive. The set of primary light colours with which we are most familiar are red (R), green (G), and blue (B). One way to think about this is that we start with a black room and add our primary light sources. Red and green add together to form yellow, red and blue add to form magenta, and green and blue add to form cyan. When they are all combined, red, green, and blue are perceived as white.

Technicolor drips

The reason for our interest in primary colours is that the next version of our drip program is going to illuminate our pixels with randomly selected colours. Since we have red, green, and blue subpixels, each of which can be assigned values from 0 to 255, we have the potential for 256 × 256 × 256 = 16,777,216 (2^{24}) different hues, shades, tints and tones.

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Of course, some of these little rascals are going to be dim and lacklustre but – from our experiments in contrast at the beginning of this column – we know that we want our colours to be as bright and shiny as they can be. One way to represent colours is to use a colour wheel (Fig.3).

As we see, our three primary colours (red green and blue) can be combined to form three secondary colours (yellow, cyan, and magenta) and six tertiary colours (with more exotic names: flush orange, chartreuse, spring green, azure, electric indigo, and rose).

These 12 colours are the ones we will use in our sketch, which you can download if you wish (**CB-Aug20-04.txt**). If you compare this sketch to our previous version, you will observe that the only difference is that – as opposed to lighting our pixels with white – for each virtual drip we now use the `random()` function to select one of our 12 colour options. Once again, I've created a video showing all of this in action (**https://bit.ly/2OG9lgg**).

Next time

I must admit that I do like the coloured drips featured in our last sketch, but simply turning our pixels hard on and hard off is not very subtle and lacks a little *je ne sais quoi*. One way in which we can add a *soupçon* of sophistication is by fading the colour up, holding it steady, and then fading it back down again, so this is what we'll do in my next column. Until then, have a good one!

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

Max's Cool Beans cunning coding tips and tricks

In my previous tips and tricks column (PE August 2020), we noted that when people are first introduced to the C/C++ programming languages, one of the first data types to which they are introduced is the `int`, which stands for 'integer'. We also noted that we may decide to declare our integers as being signed or unsigned:

```
signed   int John;
unsigned int Jane;
```

A `signed int` can be used to represent both positive and negative values, while an `unsigned int` can be used to represent only positive values. Interestingly enough, the C/C++ standards don't explicitly define the size of an `int`. All they say is that an `int` should be a minimum of two bytes (16 bits). In the case of an Arduino Uno with its 8-bit data bus, the size of an `int` is indeed two bytes; in other computers it can be two bytes, four bytes, or more.

A 2-byte (16-bit) variable can be used to represent 2^{16} = 65,526 different patterns of 0s and 1s. In the case of a signed `int`, these patterns can be used to represent both negative and positive values in the range –32,768 to +32,767. By comparison, in the case of an unsigned `int`, these patterns can be used to represent only positive values in the range 0 to 65,535.

Hey, short stuff!

There are also `short` and `long` flavours of the `int`:

```
signed   short int Fred;
signed   long  int Bert;
unsigned short int Mary;
unsigned long  int Beth;
```

In the same way we assume a number like 42 to be positive without explicitly writing it as +42, the compiler will assume that an unqualified `int` is signed, which means we may omit the `signed` part of the declaration if we wish:

```
int       John;
short int Fred;
long  int Bert;
```

Similarly, if we declare something as being of type `short` or `long`, the compiler will happily assume that we are talking about integer values, so we may also omit the `int` part if we wish:

```
int   John;
short Fred;
long  Bert;
```

The C/C++ specifications state that the minimum size of a `short int` is two bytes (16 bits), while the minimum size of a `long int` is four bytes (32 bits).

Fixing the width

It can be a tad disconcerting when one first discovers that the size of the different types of integers can vary from one machine to another. The reason behind this is to allow the compiler to make use of its knowledge of the targeted processor's internal architecture to use optimal data sizes for that particular machine.

Things aren't too bad if you are a hobbyist writing code for only one processer. However, depending on the size of the numbers you are trying to represent, problems may arise if you try to port your code from a machine that supports four-byte integers to one whose integers are only two bytes in size, for example. In order to get around this, we can use the fixed-width integer types that have been available since the v11 release of C++; for example:

```
int8_t  Cuthbert; // Unequivocally 8 bits (one byte)
uint8_t Clarence; // Indubitably 8 bits (one byte)
```

There are also 16-bit (`int16_t` and `uint16_t`), 32-bit (`int32_t` and `uint32_t`), and 64-bit (`int64_t` and `uint64_t`) equivalents of these fixed-width types.

A dangerous thing

'A little knowledge is a dangerous thing,' as the old saying goes. Suppose you are writing a program for an Arduino Uno and you know that the counter you are using to control a `for()` loop will only ever count up to 100. In this case, would you be better off using an `int8_t` (8 bits) rather than an `int` (16 bits), thereby saving a byte (8 bits) in memory? For example:

```
for (int8_t i = 0; i < 100; i++)
{
    // Do something cunning here
}
```

Generally speaking, the answer is 'no'. The problem is that using a smaller variable in order to save memory may negatively impact the performance of your program. Unless you are intimately familiar with the workings of your compiler and the internal architecture of your processor, you are best advised to use an `int` and let the compiler use *its* detailed knowledge of the processor's architecture to make optimal decisions for you.

Having said this, if you do have specific requirements, then by all means use the appropriate fixed-width types. In the case of the programs for my 12 × 12 ping-pong ball array project, for example, you will observe that I declare all of my colour values as being of type `uint32_t` (ie, unsigned 32-bit integers). The equivalent would be an `unsigned long` in the case of the Arduino Uno, but I prefer to be explicit in the case of these declarations.

But wait, there's more!

I come from the days where every memory location and every clock cycle were considered to be precious commodities. Computer magazines used to have columns of cunning tricks for doing things like swapping the upper and lower four bits in a byte in the least number of clock cycles or using the smallest number of instructions or consuming the least amount of memory.

Some designers of embedded systems are pushing the boundaries of the processors they've been instructed to use. In this case, they may decide to use the *minimum width* and *fastest minimum* width types that have been supported by C since 1999 (known as C99-compliant compilers); for example:

```
int8_t Bob;         // Fixed width signed
                    // 8-bit integer
int_least8_t Dan;   // Minimum width signed
                    // 8-bit integer
int_fast8_t Sam;    // Fastest minimum width
                    // signed 8-bit integer
```

Of course, there are unsigned versions of these types, along with 16-, 32-, and 64-bit variants, but I'd advise holding off on using these little scamps until you are 100% sure you are aware of any and all implications.

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DVFB

PIC n' Mix

Mike Hibbett's column for PIC project enlightenment and related topics

Part 2: Software tools for the PIC18F

September 2020 marks the 15th anniversary of my start as a writer for the magazine. Back in 2005, articles were submitted by paper copy months in advance, followed by many iterations, all requiring that alterations still fitted within the same layout. 'If you take five letters out, add five letters in' was standard practice. 15 years later we rework articles through email but there are still many iterations to create our published output. In 15 years, editorial processes have changed, but I still recognise and remember the magazine I read as a child in the 1970s, and the authors who I was fortunate enough to work with since becoming an author. It's with great fondness I remember John Becker, my former technical editor, who was both my professional liaison with the magazine and my hero from the 1970s.

Tools for the job

So, onto this month's article, where we look at the software tools available for developing programs on Microchip PIC processors.

In the July issue we covered how we selected the PIC18F47K42 (in a 40-pin DIL package) to form the basis of our PIC18 'Experimenter' board. We chose the PIC18F47K42 through a long selection process – there are around 17,000 Microchip processors to choose from – because it offers a broad range of peripherals, in an easy-to-work-with package. It has not been used in projects within the magazine before, which makes it an interesting candidate. There has been no particular reason why it has not been used before – authors tend to stick with older processors they are familiar with – but the PIC18F47K42 offers a wide range of peripherals and lots of memory, which will make it adaptable for many different projects.

Before we delve into the hardware aspects of any designs based on this processor, we need to get the software development environment installed, and a level of familiarity established. This is true whether you are a hobbyist or a professional developer; having a complete development environment and being comfortable using it can make a huge difference to how easy it is to build a project, quickly.

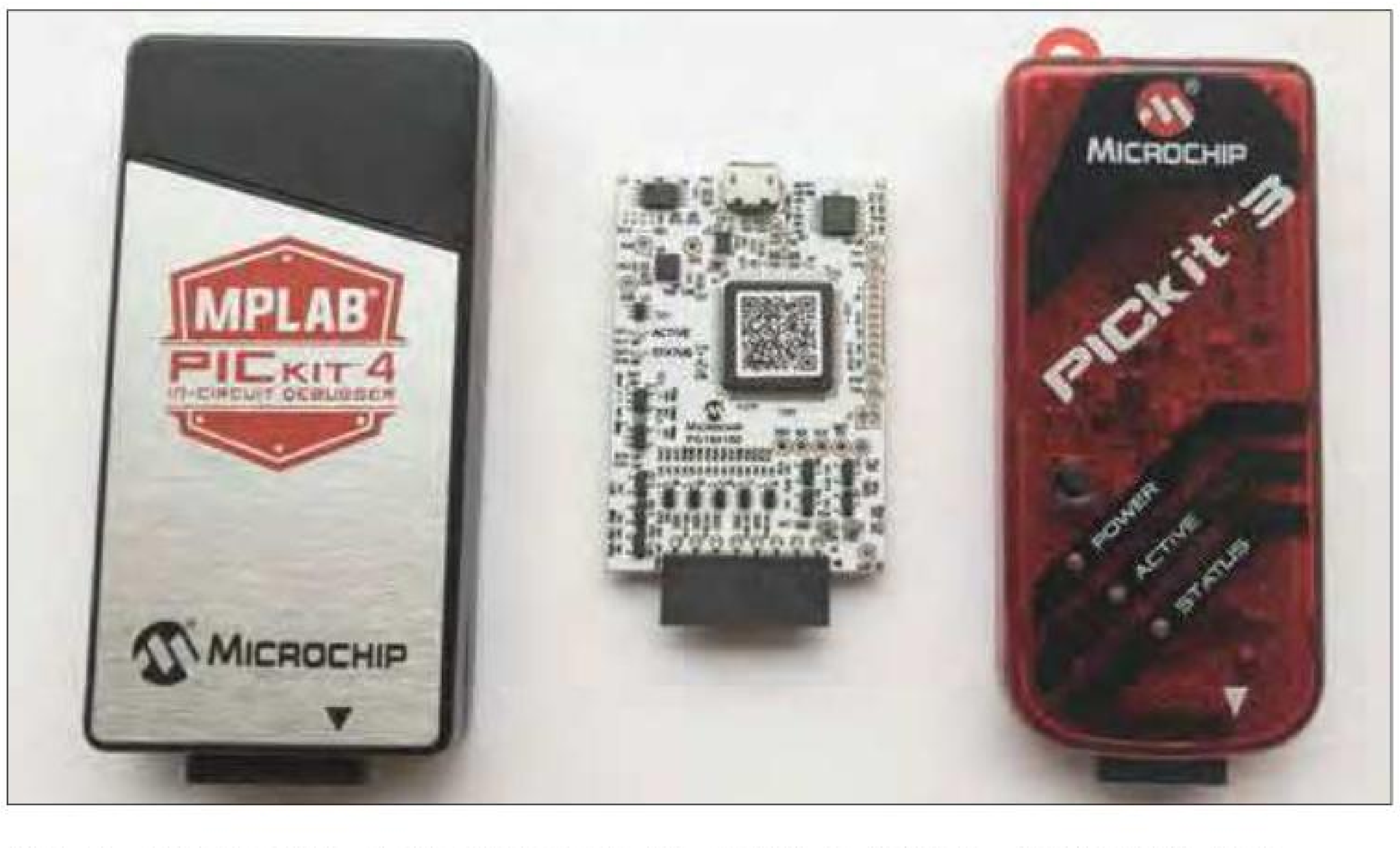


Fig.1. Microchip debuggers (l-r): PICit 4, Snap, PICkit 3. We strongly recommend the PICkit 4, but the PICkit 3 is also a good choice. The Snap, however, is too limited for this project series.

PIC vs Arduino

Developing software for the PIC processor is very different to platforms such as the Arduino, which comes with over a hundred libraries and example applications. Microchip focus on providing a few key low-level driver libraries, and just a handful of example applications. Their low-level documentation for the processor is excellent however, so writing any new driver libraries is possible, and allows you to fine tune your software to match your application's needs, and the capabilities of the processor. It does, however, require that you understand more about what is going inside the processor. That's fine – it's the reason why we experiment with PIC processors, to learn more about what is going on. If this learning opportunity does not interest you and you only want to get a project up and running as quickly as possible, then an Arduino development system would be more appropriate. The benefit of learning more about the processor itself is that it will provide you with many more options to solving a design challenge, and with more complex designs, enable you to create a solution that would not be possible on a simple Arduino platform.

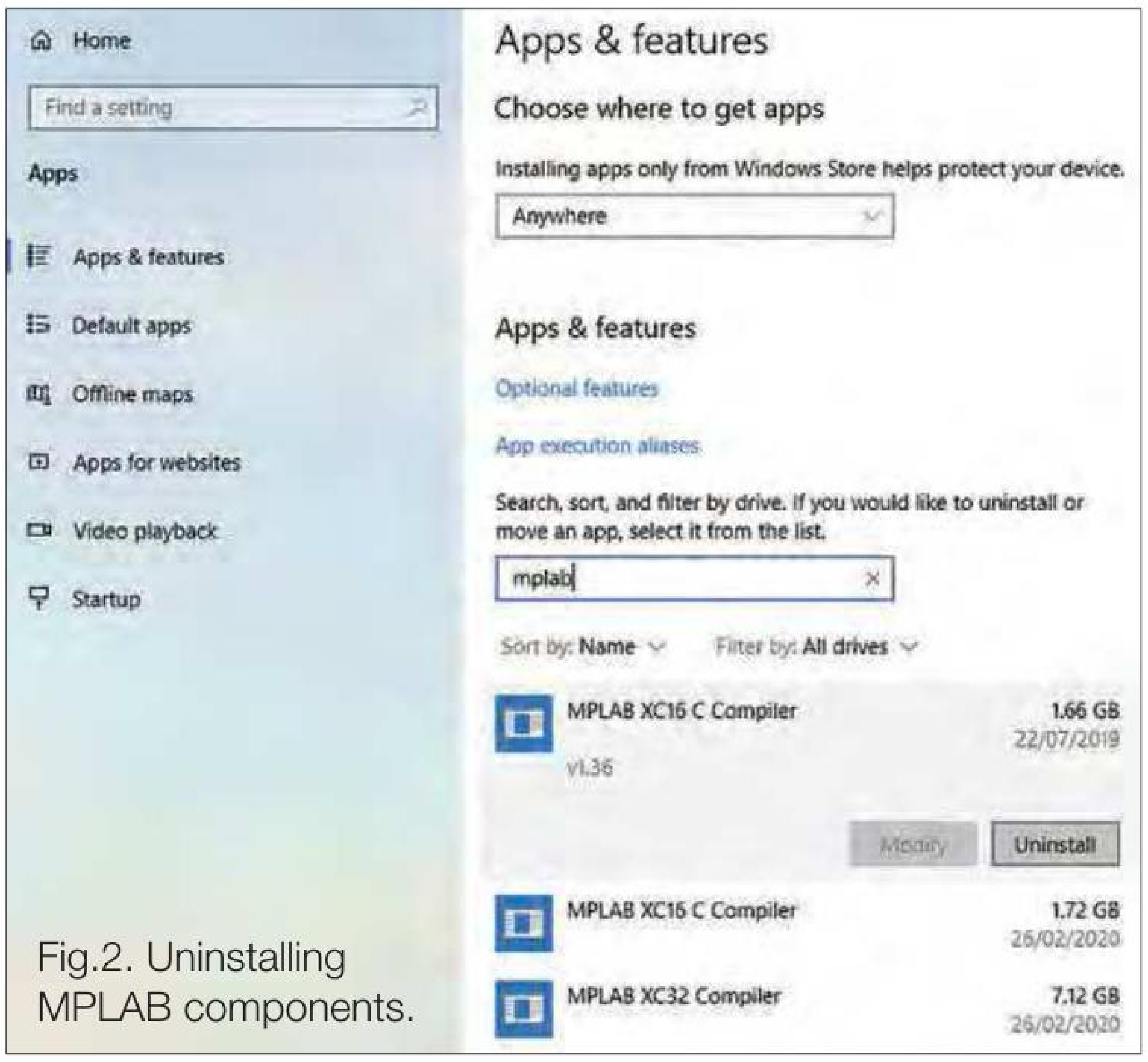
MPLAB X IDE

Developing software requires a number of different tools. At a minimum, you need the following:

- Text editor
- Compiler
- Driver libraries
- Programmer/debugger
- Programming interface

To pull all these requirements together Microchip have created an Integrated Development Environment (IDE) called MPLAB X, which combines the code editor, programmer and debugger capabilities into a single application. The IDE is really a framework application that allows other PC programs to be configured, run and the results viewed all within the same application. It's possible to run the compiler, see a list of error messages from that complier in an IDE window, that when you click the mouse on them will cause the offending line of code to come up in the editor window. Using MPLAB X is not a hard-and-fast requirement; you could edit your programs using your favourite editor, then compile the program in a command shell. However, Microchip's IDE simply makes the process easier and quicker to perform.

In addition to MPLAB X we will also need a compiler. This is a standalone application that will convert our programs, written in text files in the 'C' programming language, into the



Apps & features

Choose where to get apps

Installing apps only from Windows Store helps protect your device.

Anywhere

Apps & features

Search, sort, and filter by drive. If you would like to uninstall or move an app, select it from the list.

mplab

Sort by: Name Filter by: All drives

MPLAB XC16 C Compiler v1.36	1.66 GB 22/07/2019
MPLAB XC16 C Compiler	1.72 GB 26/02/2020
MPLAB XC32 Compiler	7.12 GB 26/02/2020

Fig.2. Uninstalling MPLAB components.

binary format that the processor understands. Microchip provide three different compilers for the different PIC families:

- MPLAB XC8: all 8-bit PIC devices, from the PIC10F to the largest PIC18F
- MPLAB XC16: all 16-bit PIC devices, PIC24, dsPIC33
- MPLAB XC32: all 32-bit PIC devices, such as the PIC32

These have to be download separately to MPLAB X but are very easy to install.

The programmer and debugger capabilities are pre-built into MPLAB X and do not require a separate download.

With the above components you have the minimum software necessary to start developing programs. However, one further download provides a set of goodies – example drivers and sample applications – that will make our life easier, especially if we are using UART, I^2C or SPI communications. Confusingly, Microchip provide three different software packs to fulfil this, called MLA, Harmony and MCC.

MLA is the old and now deprecated 'Microchip Libraries for Applications', which has been replaced by MCC, 'Microchip Code Configurator'. MCC is used with 8-bit devices, such as the PIC18F family. Harmony is a similar pack of libraries, but targeted to 32-bit devices, so of no interest to us today. We will be installing MCC and will be making frequent use of it.

In summary, our installation process will be MPLAB X, the XC8 compiler, followed by MCC. If you plan to use a 16-bit or 32-bit processor in the future, feel free to install those two compilers too, as they can co-exist with no issue. MPLAB X is smart enough to choose the correct compiler for your project, as we will show later.

Last, but not least, Microchip have helpfully made these tools available not only for Windows, but also Linux and macOS PCs.

…and the cost?

The great news is that the MPLAB X IDE and the MCC libraries are free – however, the situation is a little more complicated with the compiler programs. They are provided for free, but you can pay to unlock commercial/professional features. The professional versions provide additional optimisations in the translation to a code binary, and this can result in a 20-30% improvement in code space use compared to the 'free' version of the compiler. There may also be some reductions in the amount of RAM used. In our opinion, for hobbyists, these improvements do not justify a fairly expensive purchase of a professional compiler licence. The 'free' version is not crippled in any way; all compiler features are available – the difference is in the optimisations the compiler performs to reduce code size. This would be important if you were building a large number of products and would like to use smaller, cheaper versions of a microcontroller. For hobbyists, we can simply purchase the device with larger memory that costs perhaps 50p more. To reiterate, you are not missing out on features by avoiding an expensive purchase.

Programming interface

Microchip processors require a small piece of hardware, called a 'debugger', to transfer programs to a device. The tool of choice is the PICkit 4 from Microchip, which costs around £55. The previous generation debugger, the PICkit 3, can also support the processor we are using and is cheap secondhand on eBay (from £12). Clones of the PICkit 3 can be purchased on eBay for as little as £15, but we strongly recommend using the official device. We will focus on using the PICkit 4 in this and future articles. It's a solid product that should last for years – we have never had a Microchip debugger fail on us in 25 years, the only issue is that every decade or so new processors become available that require a programmer update, but you will be required to update your programmer only if you want to use those new ICs.

There is a lower-cost debugger available from Microchip called the 'Snap', which costs around £18. It can program the PIC18F47K42 but has limited features, comes as just a bare PCB and in our opinion is just too basic for our plans. You can see these three debuggers in Fig.1.

On a historical note, our first emulator for the PIC16 series of processors cost around £900 back in 1995!

The debugger is connected to the PC via a USB cable (supplied with the debugger.) Five signals connect the debugger to your target PCB via an 8 pin 0.1-inch pitch header socket. Hook-up wires can be used to make the connection, but we prefer to fit an 8-pin header strip to our boards and plug the debugger in directly – we will provide an 8-pin header strip on our experimenter board.

Installation preparation

In the following sections we describe the setup for PCs running the Windows OS, as this is the most common setup. The installation process for other operating systems will be similar – check online for exact details if you are using Linux or macOS operating systems.

Before we install the latest versions of the software (Microchip update their software tools frequently) we will want to remove any previous versions. Your creations will not be deleted by these steps, just the very large IDE and compiler install files, which can add up to many gigabytes of disk space. If you do not have Microchip tools installed you can skip to the 'Installation' section below.

To remove earlier versions, first click on the 'Start' button, then type 'Add', and select 'Add or Remove programs'. From the drop-down list that appears, as shown in Fig.2, type 'mplab' in the search box to filter just the Microchip software components. Now *remove* all 'Microchip' installed features. You will have to do these one at a time. Left click on an item in the list, then click the 'Uninstall' button. Follow the instructions, and when done, repeat for all the other entries. We had about a dozen entries for multiple old versions of the toolchain, so this bit of spring-cleaning freed up over 10GB of disk space.

Installation

We start by installing the latest version of MPLAB X IDE, which at the time of writing is version v5.40. In your browser, go to: **https://www.microchip.com/mplab/mplab-x-ide** and scroll down to the 'Downloads' tab. Click on the text 'MPLAB X IDE v5.40' to start the download. Don't worry if the version has been updated, changes are likely to be minimal. Microchip make regular updates to their software tools (typically when new processors

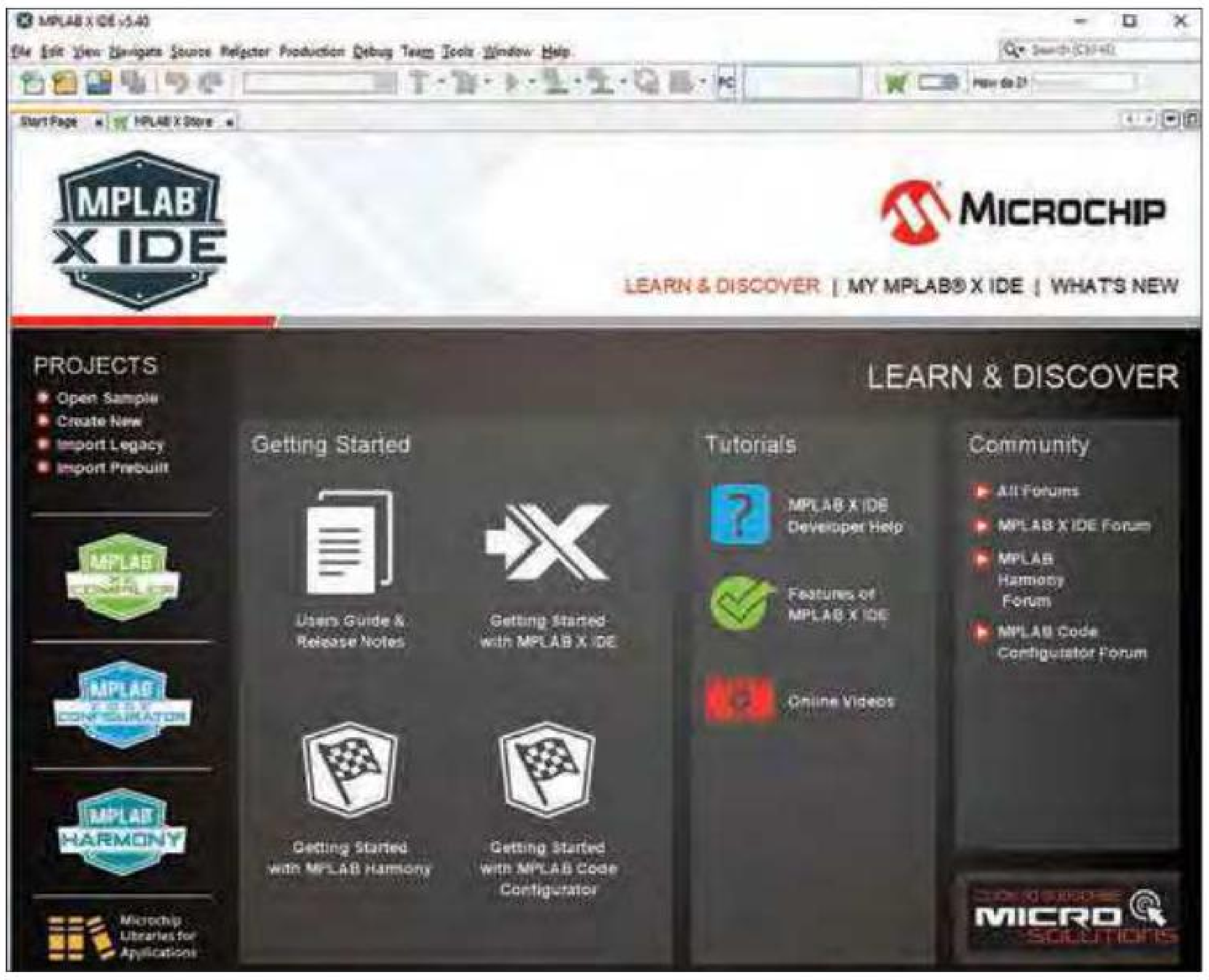

MPLAB X IDE v5.40
File Edit View Navigate Source Refactor Production Debug Team Tools Window Help
Start Page
MPLAB X Store
MPLAB X IDE
MICROCHIP
LEARN & DISCOVER | MY MPLAB® X IDE | WHAT'S NEW
PROJECTS
Open Sample
Create New
Import Legacy
Import Prebuilt
LEARN & DISCOVER
Getting Started
Users Guide & Release Notes
Getting Started with MPLAB X IDE
Getting Started with MPLAB Harmony
Getting Started with MPLAB Code Configurator
Tutorials
MPLAB X IDE Developer Help
Features of MPLAB X IDE
Online Videos
Community
All Forums
MPLAB X IDE Forum
MPLAB Harmony Forum
MPLAB Code Configurator Forum
MPLAB HARMONY
Microchip Libraries for Applications
MICRO SOLUTIONS

Fig.3. The MPLAB X main window.

are added, but also for bug fixes and improvements.) MPLAB has been in development and maintained for many years.

Once downloaded, double click the file to start the installation process. Other than clicking to accept the software licence terms, accept all defaults. We recommend that you do not change the installation folder as this will make installing the compiler and MCC libraries difficult.

Close to the end of installation a Windows Security pop-up will be displayed. Click 'Install' to install the hardware drivers for the debugger tool. At the end of installation, a Setup pop-up appears; *untick* the three checkboxes – we will perform these steps manually. Click 'Finish' to complete the installation.

Now for the compiler; in your browser, go to: **https://www.microchip.com/mplab/compilers**. and scroll down until you see the 'Compiler Downloads' tab. Click on that, and then click on 'MPLAB® XC8 Compiler v2.20'. Again, this version may have been updated by the time you get to it, so it may be v2.21 or similar. This is fine; compiler updates rarely impact users of the tool, and just provide minor bug fixes. Again, once downloaded, double-click on the file to start installation. Other than clicking to accept the software licence terms, accept all defaults. The installation process will update MPLAB so that it 'knows' a compiler has been installed.

We can now start MPLAB X IDE by double-clicking on the newly created desktop icon, or by clicking on the Windows 'Start' icon and typing 'mplab x'. Be careful at this point – the MPLAB X IDE installation process installs another useful application, a programmer utility, that is amusingly called MPLAB X IPE. Given this differs by only a few pixels on the screen, it's easy to click on the wrong one. We ended up deleting the desktop icon for IPE by right-clicking on the desktop icon and selecting 'Delete'. This removes the short-cut icon from the desktop, but leaves the program installed and ready to launch from the Windows Start menu.

If you've previously installed MPLAB you will be presented with a pop-up box asking whether you would like to import old settings from the previous installation. We recommend you do not do this – we want to start with a clean sheet. So click 'No' if presented with that message.

You may get a warning from your virus protection software that **mplab_ide64.exe** is attempting to access the network. Go ahead and click 'Allow access', as we trust Microchip, and this feature enables MPLAB to check for updates to software automatically.

You should now see the main IDE window, as shown in Fig.3. Two windows are opened on start-up, 'Start Page' and 'MPLAB X Store'. Go ahead and close these windows by clicking the 'x' on the right-hand side of the tabs.

Adding MCC

Our final installation step is to bring in MCC – the drivers that we can add to our projects. MCC is not just a set of source files, it's a complete GUI (graphical user interface) that helps simplify the process. Confusingly, there are several ways to install MCC; we will do it within MPLAB X itself, as the IDE has a 'plug-in' tool already built in.

Click on the 'Tools' menu option, followed by 'Plugins' (*not* 'Plugins Download).

Click on 'Available Plugins' and scroll down until you see 'MPLAB Code Configurator'. Click the check-box, then click on the 'Install' icon at the bottom of the window, as shown in Fig.4. Click 'Next', then accept the licence agreement, and click 'Next' to start the installation process. MPLAB X will now download MCC and install it; so this may take a minute or two. At the end, MPLAB X will need to restart, so just click 'Finish'. MPLAB X will restart automatically after a few seconds and complete the installation process. We are now ready to create our first project.

If you have a PICkit 4 debugger, go ahead and plug that in now. The front of the device should illuminate blue once connected.

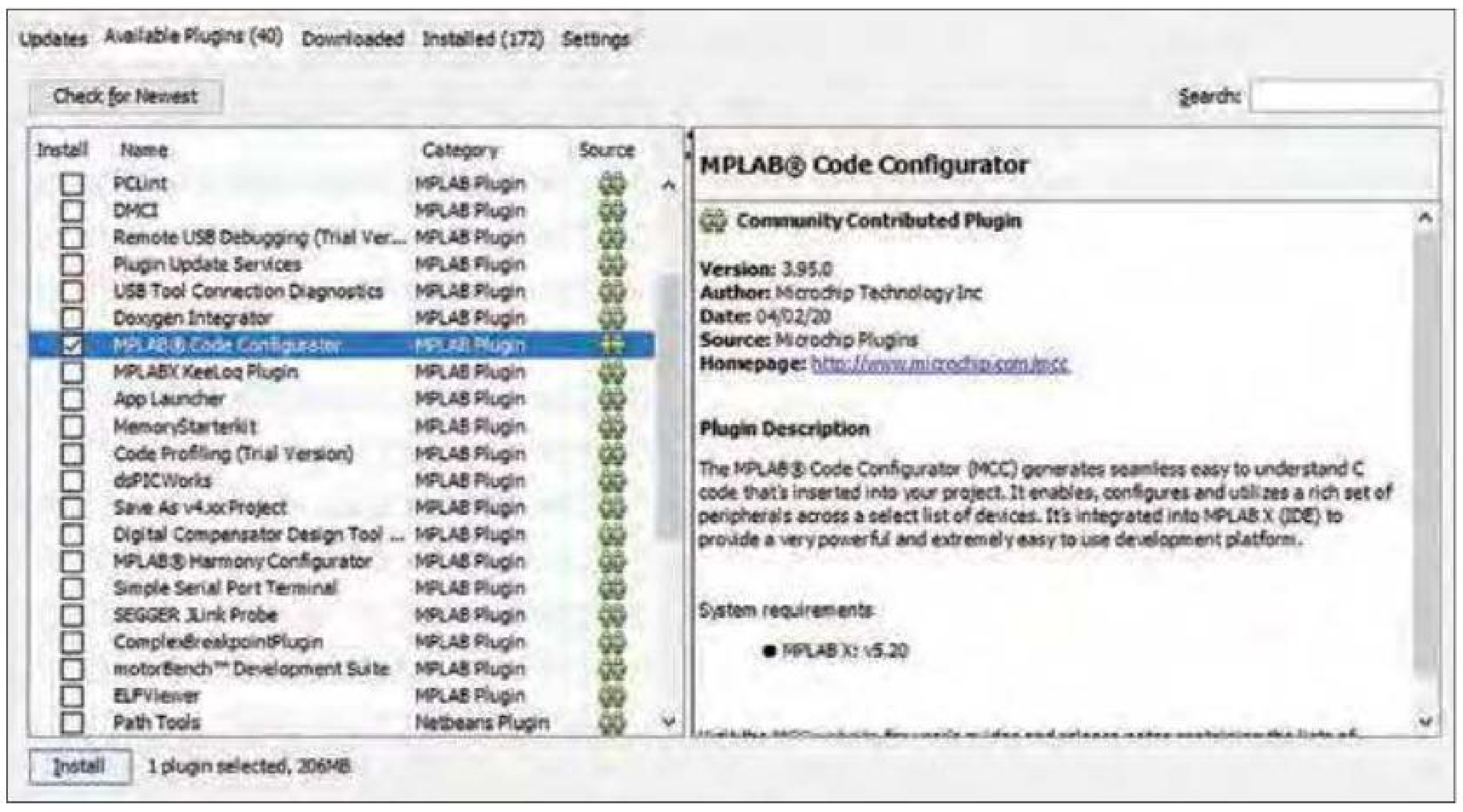
In MPLAB X IDE, click on the 'File' menu option, followed by 'New Project...'. In the 'Categories' section of the pop-up window leave 'Microchip Embedded' highlighted and click on 'Standalone Project' followed by 'Next'. In the highlighted 'Device:' field, type in the name of our processor, 'PIC18F47K42'. If you have a PICkit 4 plugged in then select it from the 'Tool:' drop-down list. Click 'Next'. We can select the compiler we will be using; XC8. This should be shown in this list, so click on that and then click 'Next'.

Finally, we have to give our project a name (type 'test') and specify where this project will live on your PC's disk. This directory will hold your project settings and all the source files you create. For now, it is an empty project and we shall leave MPLAB X at this point and return to it once we have completed our hardware design.

Coming up next

In the next article we will start the design of our experimenter PCB. Our intent is to make clear the thought process going into the design of the board and explore the capabilities of the processor. We will be focusing on *using* the processor rather than diving into the details of internal processor peripherals. We are going to cover: GPS location reporting, digital compass, various display technologies, speech output, PC connection via USB, Wi-Fi communication, interfacing with Amazon Alexa, Servo motor control, analogue input.

Some are more ambitious than others, but it will be a fun journey and we hope you will join in. The PCB will be available from our usual suppliers, and full PCB Gerber and design files available should you wish to etch your own, although as a double-sided design this might be challenging.


Updates
Available Plugins (40)
Downloaded
Installed (172)
Settings
Check for Newest
Search:
Install
1 plugin selected, 206MB

Install	Name	Category	Source
☐	PCLint	MPLAB Plugin	
☐	DMCI	MPLAB Plugin	
☐	Remote USB Debugging (Trial Ver...	MPLAB Plugin	
☐	Plugin Update Services	MPLAB Plugin	
☐	USB Tool Connection Diagnostics	MPLAB Plugin	
☐	Doxygen Integrator	MPLAB Plugin	
☑	MPLAB® Code Configurator	MPLAB Plugin	
☐	MPLABX KeeLoq Plugin	MPLAB Plugin	
☐	App Launcher	MPLAB Plugin	
☐	MemoryStarterkit	MPLAB Plugin	
☐	Code Profiling (Trial Version)	MPLAB Plugin	
☐	dsPICWorks	MPLAB Plugin	
☐	Save As v4.xx Project	MPLAB Plugin	
☐	Digital Compensator Design Tool ...	MPLAB Plugin	
☐	MPLAB® Harmony Configurator	MPLAB Plugin	
☐	Simple Serial Port Terminal	MPLAB Plugin	
☐	SEGGER JLink Probe	MPLAB Plugin	
☐	ComplexBreakpointPlugin	MPLAB Plugin	
☐	motorBench™ Development Suite	MPLAB Plugin	
☐	ELFViewer	MPLAB Plugin	
☐	Path Tools	Netbeans Plugin	

MPLAB® Code Configurator

Community Contributed Plugin

Version: 3.95.0
Author: Microchip Technology Inc
Date: 04/02/20
Source: Microchip Plugins
Homepage: http://www.microchip.com/mcc

Plugin Description

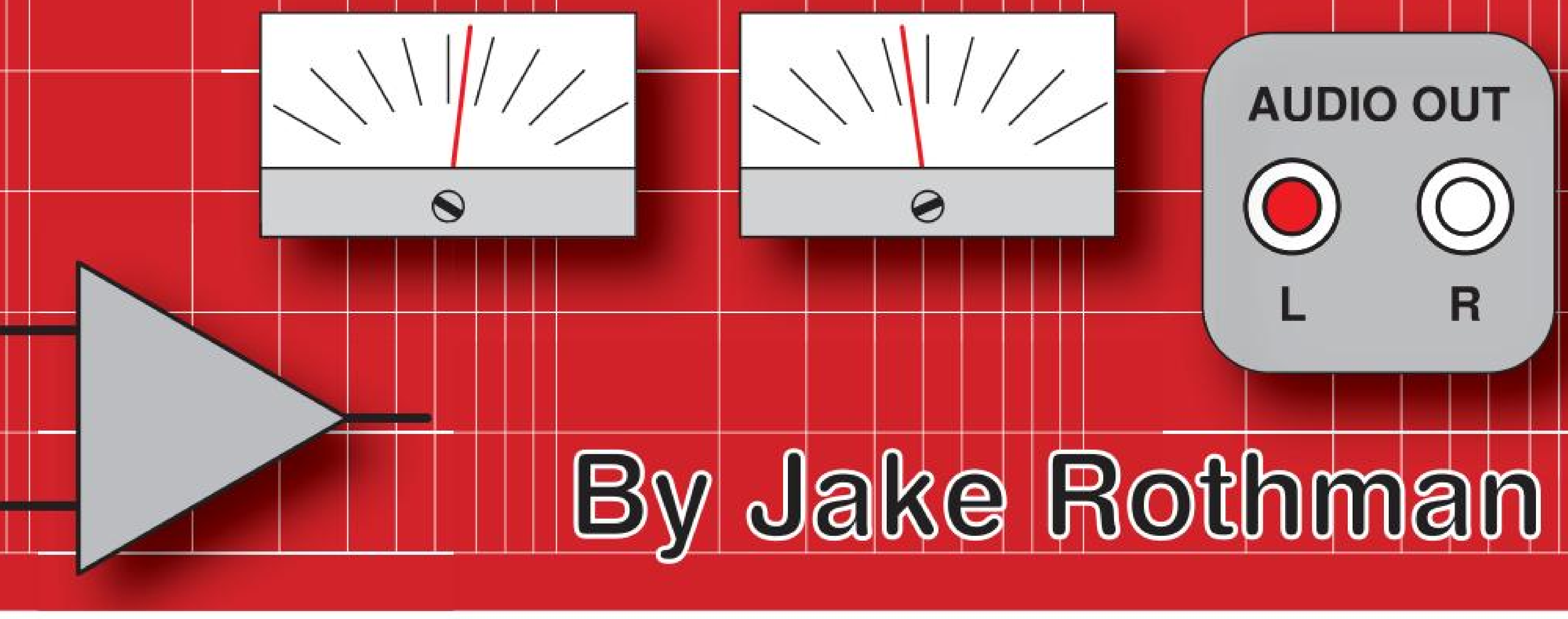
The MPLAB® Code Configurator (MCC) generates seamless easy to understand C code that's inserted into your project. It enables, configures and utilizes a rich set of peripherals across a select list of devices. It's integrated into MPLAB X (IDE) to provide a very powerful and extremely easy to use development platform.

System requirements

- MPLAB X: v5.20

Fig.4. MCC installation via MPLAB X.

AUDIO OUT



By Jake Rothman

Low-noise Theremin Power Supply – Part 2

Last month, we discussed the importance of a low-noise power supply for sensitive audio applications, such as a Theremin. This month, we will move on from theory and actually build one. In fact, we will offer not just one, but four circuits based around the same flexible PCB, supplying different voltage outputs.

Basic design

For linear power supplies we have to factor in all the losses, as shown in Fig.15:

- Headroom required by the regulators, (the minimum difference between the input and output voltages is around 2V for the LM317 used here).
- Regulation figure or the voltage droop of the transformer at the expected load current.
- Total forward voltage drop (V_f) of the rectifier diodes (1.4V for silicon or 0.5V for Schottky devices).
- Minimum input voltage at the bottom of the ripple waveform. This can be minimised by fitting the biggest smoothing capacitors (C10/13) physically possible in a small PSU, typically 1000 to 2200µF.

Since it is a bridge-rectifier/capacitor circuit, the output voltage is theoretically equal to the peak AC (×1.4 the RMS input voltage), which gives us a useful boost. However, there is no such thing as free energy, this comes from a corresponding rise in the current drawn. All these factors limit the real-world current that can be drawn to around 120mA if the regulated voltages are set to around 9V and 15V. At least we won't need any heatsinks on the regulators at this level. This circuit is thus ideal for powering the Theremin or other sensitive circuits and we also have an isolated 15V supply for the audio amplifier, which avoids interaction between the two sections.

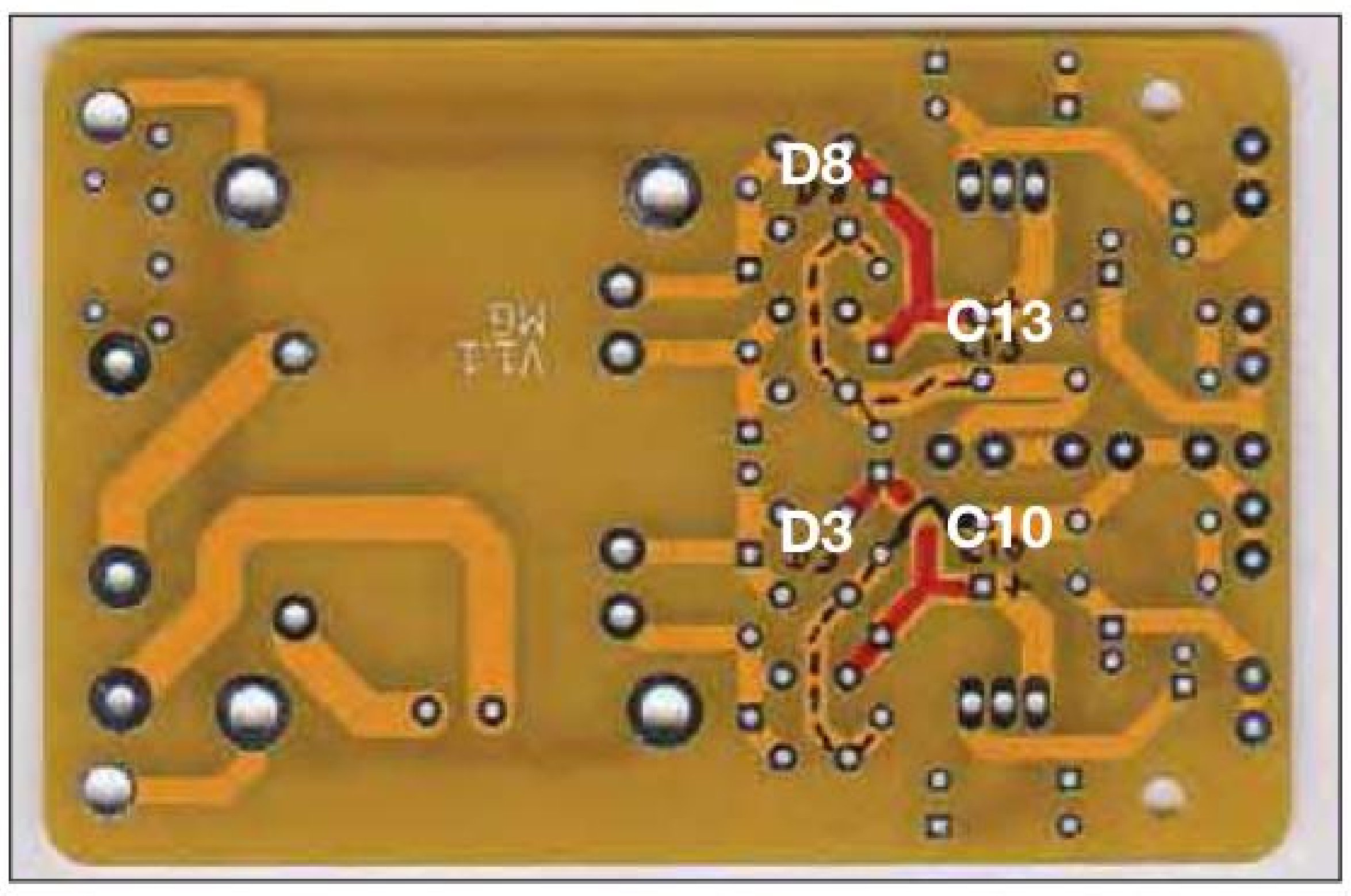


Fig.16. PCB tracks from the rectifier to the smoothing capacitors. These have nasty pulses on them due to charging currents. Nothing else must be connected or 100Hz noise will result. Note the following on the above PCB: the track jumps from D3 to C10 on the other side of the board. (Red is the positive (+) line and the black dotted is the negative line (–)

PCB layout

Getting low hum on the output is dependant on the PCB track layout. It is very important to ensure the charging pulses from the rectifiers to the smoothing capacitors do not get superimposed on the output. This can easily be achieved by making sure the two lines from the rectifier go directly to the smoothing capacitor pins with no other connections along these tracks. The lines to the regulators then have to be taken directly from the capacitor pins. This practice is called 'noding' or 'starring'. The two paths on the PCB are shown in Fig.16. There is no provision for the Zobel network on the PCB, since the components are rather large and the Theremin works fine without it. If you do want one, it will have to be hard-wired to the board, possibly using a small board as shown in Fig.31. Note that only one Zobel network will be needed for dual rails, since the two windings are well-coupled magnetically via the transformer.

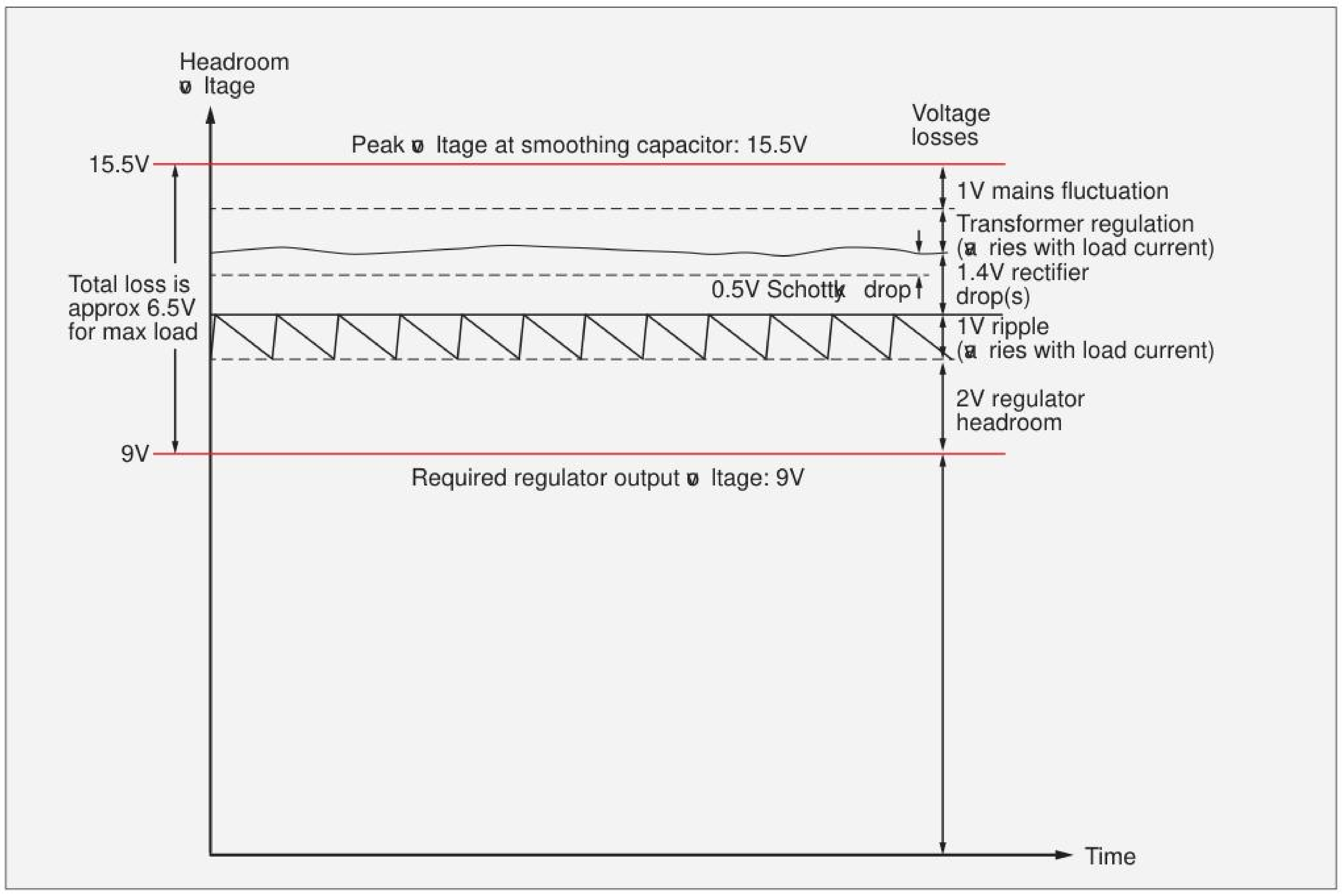


Fig.15. Taking account of the cumulative losses in linear power supply design.

Regulators

The low noise of the LM317 voltage regulator has been recognised for years by the audio community. In the 1980s it was expensive, now it is a cheap commodity component. It has lower noise because it uses a band-gap voltage reference rather than a Zener diode. The reference can also be decoupled with an external capacitor, which knocks the noise down by a further factor of 10. A classic example of a band-gap reference is the difference between silicon and germanium diode junctions being set to 0.43V by adjusting the currents flowing through them. The 0.43V is the point of maximum temperature stability. In the case of the LM317, the band-gap is made from

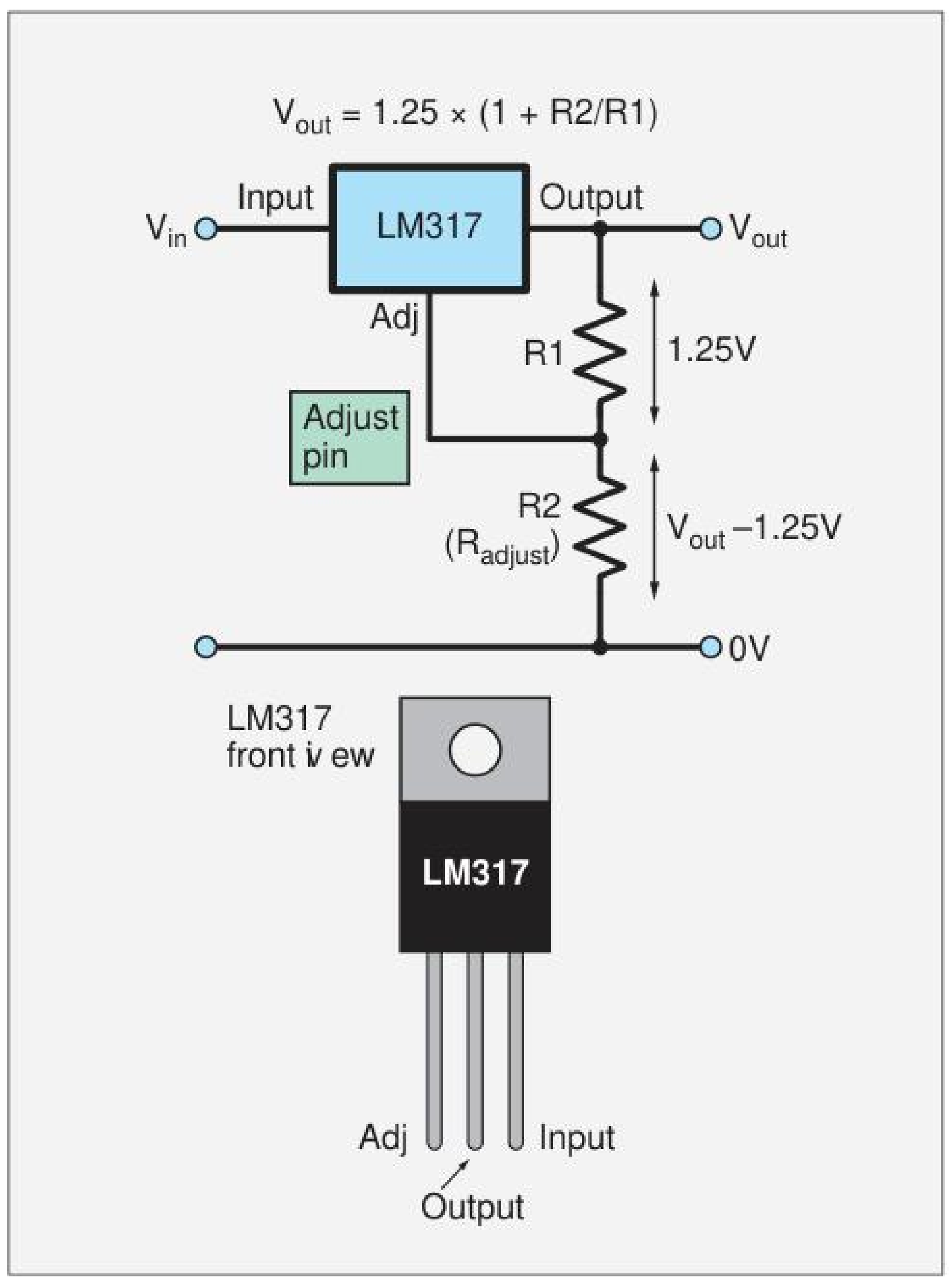


Fig.17. Basic LM317 voltage regulator circuit. A relatively low-resistance voltage-setting divider reduces variations due to variations in the regulators quiescent current that flows out of the adjust pin.

two dissimilar silicon junctions giving a reference of 1.25V using one of the late Bob Widlar's unique circuits. (He's worth looking up on Wikipedia). By scaling this voltage using a resistor network, any desired voltage from 1.2 to around 32V can be obtained, as shown in the basic circuit in Fig.17. The equation is basically the gain of a non-inverting op-amp multiplied by the 1.25V voltage reference:

$$V_{out} = 1.25[1+(R2/R1)]$$

R1 is usually 120Ω to 240Ω; note that 120Ω uses more current, but gives a more predictable voltage.

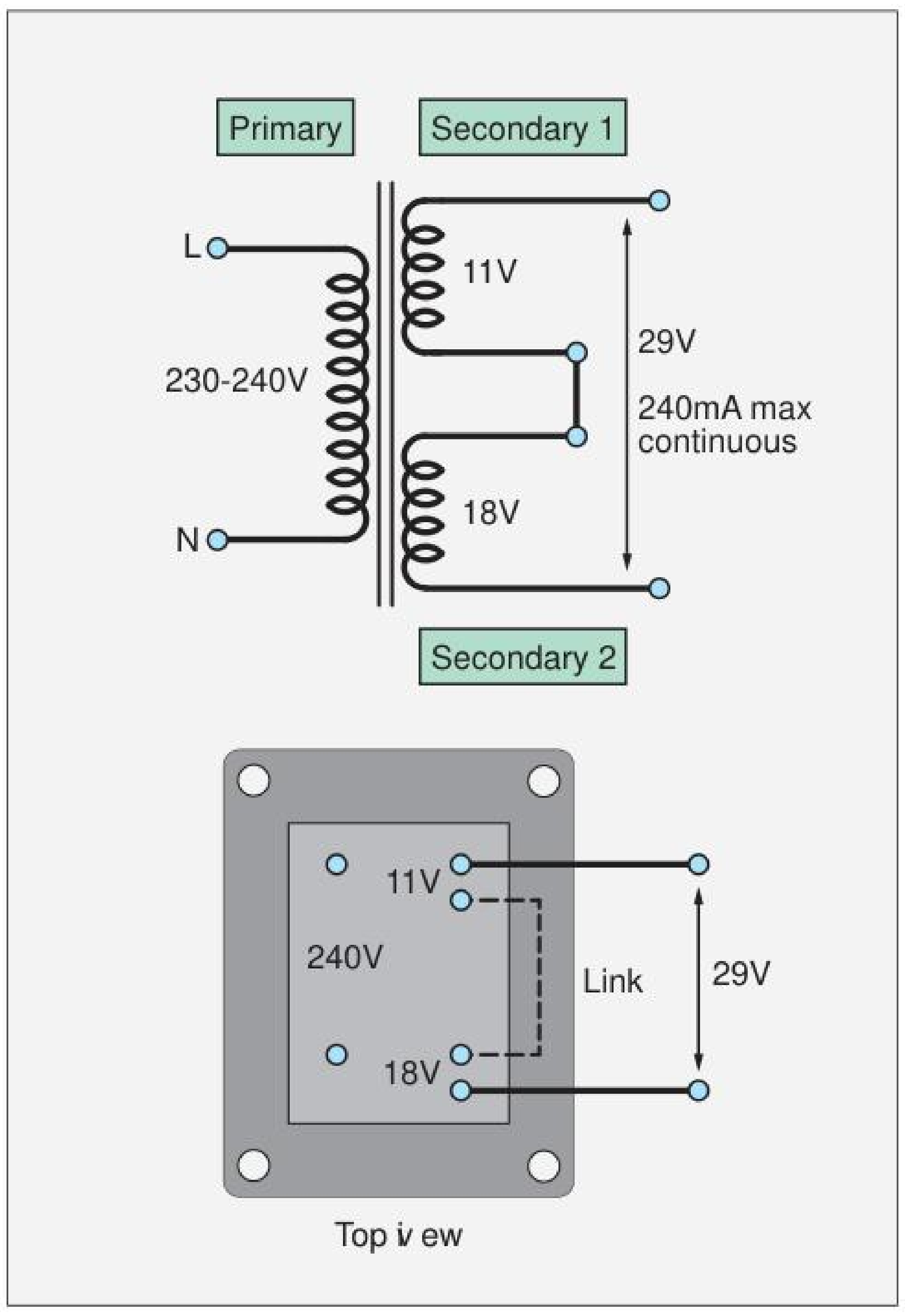


Fig.18. The transformer secondaries can be connected in series if needed to get a single-rail higher voltage supply up to 30V.

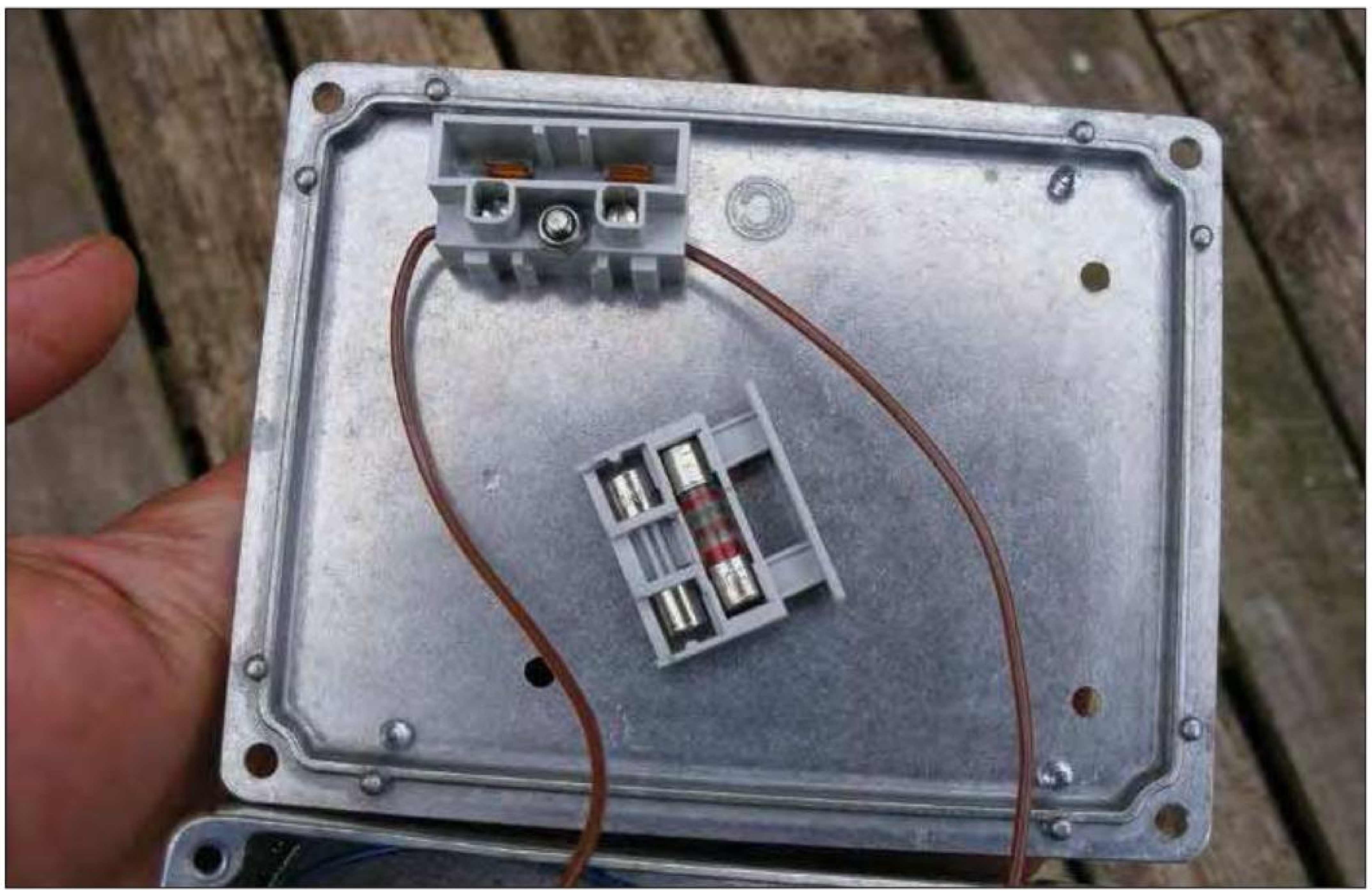


Fig.19. A suitable internal fuse holder – this is insulated so you can't get a shock off it. It must be placed in the live wire.

If you want an on-line calculator then **https://circuitdigest.com/calculators/lm317-resistor-voltage-calculator** is good. Note the overall tolerance of the set voltage of the LM317 is about 10%, so a bit of resistor tweaking may be needed. Make the calculated R2 value a bit bigger than required, and then put resistors in parallel with R2 to tweak its output down to create the required voltage.

Here's a list of some typical voltages and the associated value of R2 (R1 = 120Ω):

5V	360Ω
6V	453Ω E96
7.5V	600Ω
9V	750Ω
12V	1kΩ
15V	1.3kΩ
18V	1.6kΩ
22V	2kΩ
24V	2.2kΩ
25V	2.32kΩ E96
28V	2.55kΩ E96
30V	2.7kΩ (33kΩ in parallel with 3kΩ)

Some values are from the E96 series. These are inexpensive now, about 3p from Mouser; eg, Part no. MFR-25FBF52-2K32.

Above 15V, the transformer windings will have to be put in series (see Fig.18) unless the current drawn is very low. (With Schottky diodes and around 30mA load it is possible to get 18V.)

Protection

Over-current

The LM317 has a short-circuit current limit of 1.5A, assuming a massive heat sink. This is so high that it's useless, something else usually blows up first. Here we will have to use a fuse in series with the primary. A low value (250mA) time-delay is about right. Don't just rely on the 13A fuse in the mains plug. This can be wired as shown in Fig.19 or you can use a panel-mounted holder.

Thermal

A 127°C or 105°C non-resetting thermal cut-out is placed in series with the primary to guard against the transformer overheating. It's physical placement against the earthed laminations is shown in Fig.20. If it trips it has to be replaced.

Over-voltage

The absolute maximum input voltage to the LM317 is 37V. If the secondaries are connected in series (Fig.24), the off-load voltage can breach this so replace the standard protection diodes with Zeners.

Components

The devices are not hard to source – see the transformer notes below and in *Part 1*. Explain versions. This list is for the +9V/+15V version. there are some changes for the +30V version marked with an asterisk, '*'.

Resistors

R1	1kΩ 5% 0.5W
R3, R5	120Ω 1% 0.25W

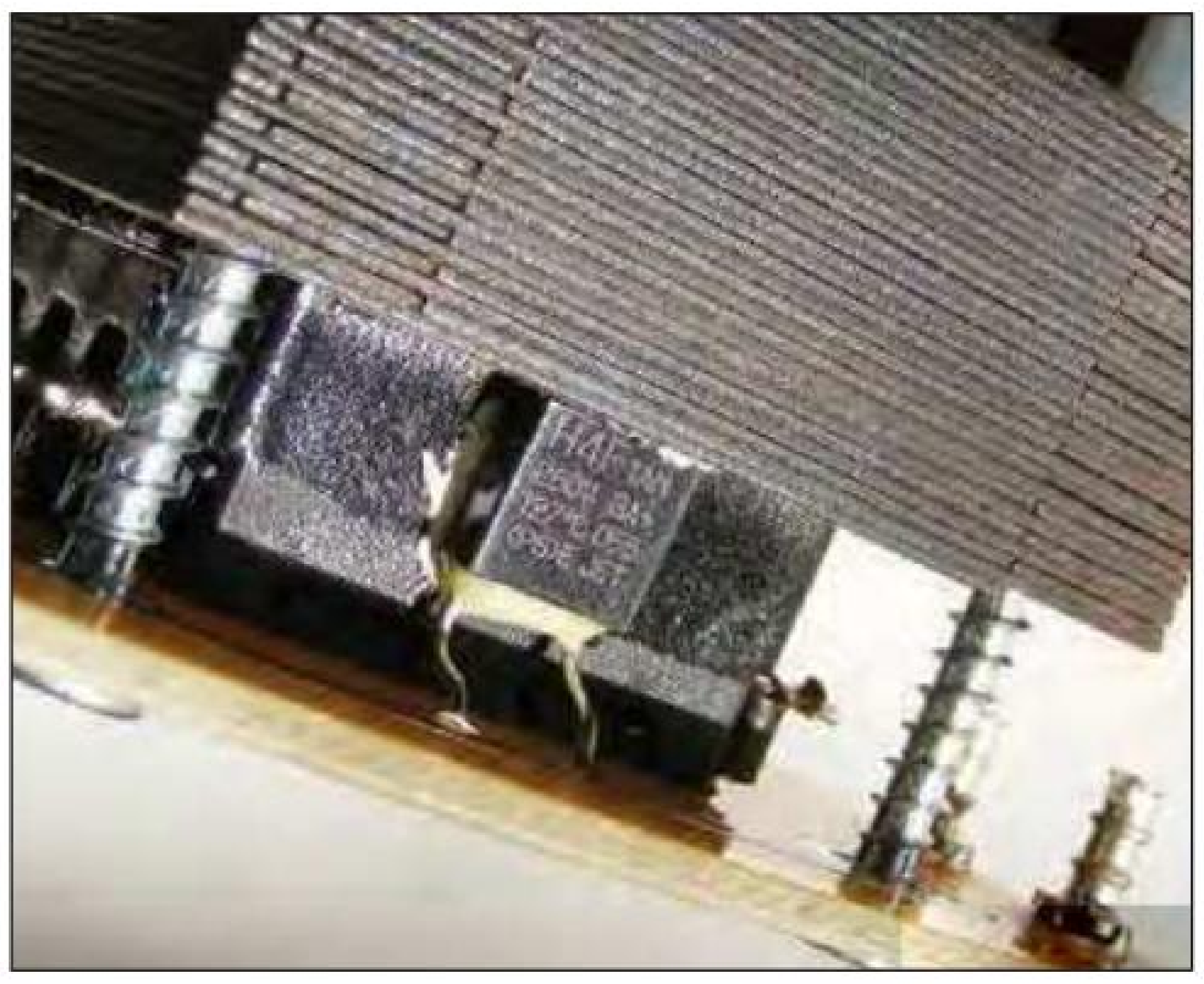


Fig.20. Location of the thermal cut-out; vital if you use a plastic or wooden case.

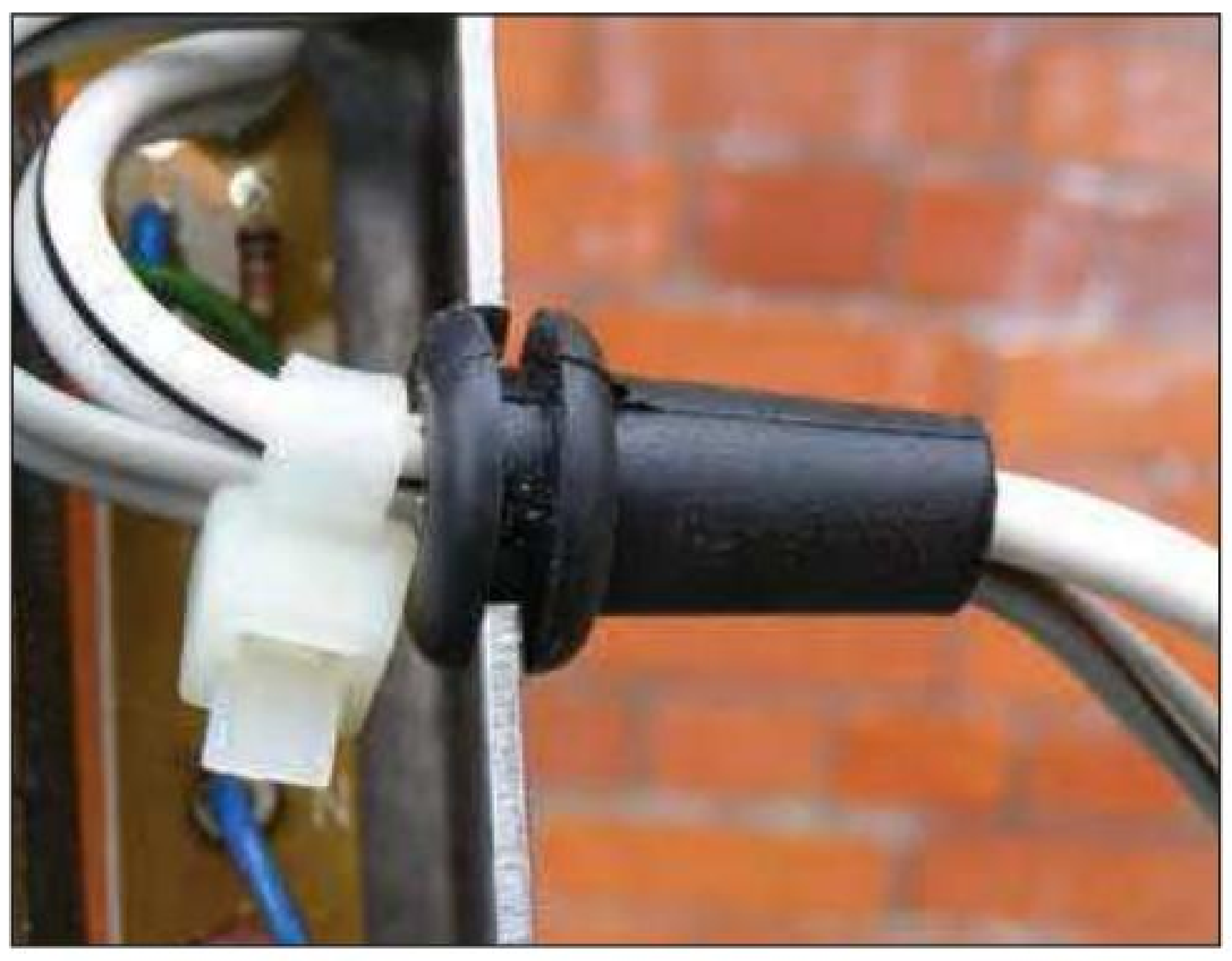


Fig.21. The output cable of DC power supplies is often the polarised figure-of-eight type, typically cheap speaker cable. Note the rubber grommet.

R2, R4	See above table for required values (use 0.25W, 1%)
R2a*	33kΩ
Rz	2.2Ω, 0.25W, 5% (optional Zobel)

Capacitors

C1	10nF ceramic, 5mm X7R
C2-C9	100nF ceramic, 5mm X7R
C10	2200µF 25V (*1000µF, 50V)
C11,12	100µF 25V (*35V)
C13	2200µF 25V (*1000µF, 50V)
C14,15	100µF 25V
Cz	4.7µF, 63V any non-polarised type (optional Zobel)

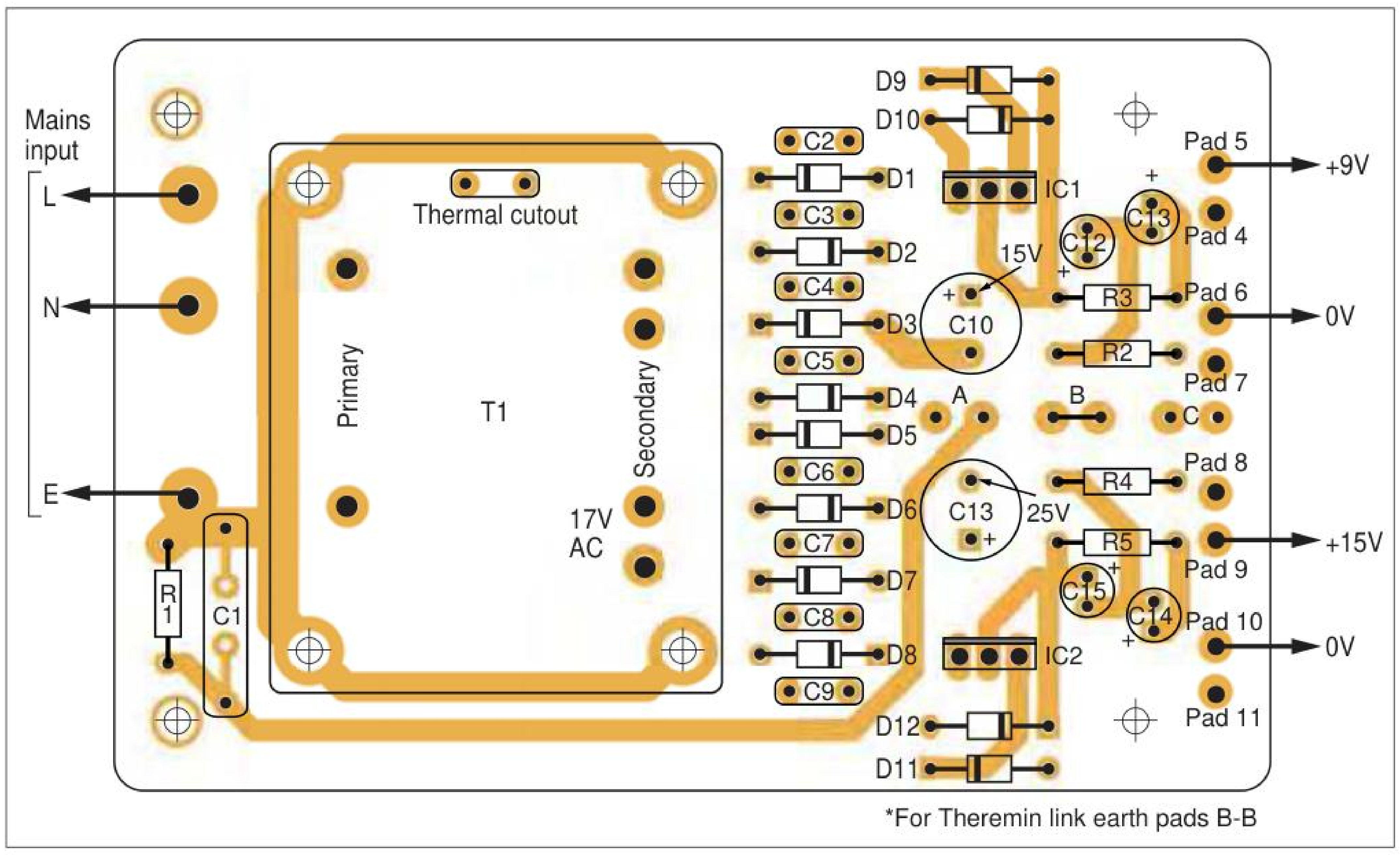
Note: the electrolytic capacitors determine the life expectancy of linear power supplies, so use long-life types (> 2000 hours at 105°C) such as those by Nichicon, Kemet and Panasonic. They don't need to be low equivalent series resistance (ESR) types (see capacitor 'tuning' later). All electrolytics used are radial.

Semiconductors

IC1,2	LM317T positive adjustable voltage regulator
D1-D8	SB40 1A 40V Schottky rectifiers (used where low voltage drop is required. If 1.4V can be accommodated then use 1N4002. For lower noise use UF4002)
D9-D12	1N4001 (*22V BZY61, 1.3W zener)

Miscellaneous

- Fuse holder, Camden Boss single fused terminal block (Rapid 21-0740 with T250mA 20mm fuse)
- IEC connector (Rapid Bulgin 51-4336 or Chinese 23-0100)
- Rubber boot (Cliff Rapid 23-0350)
- M3 × 40mm fixing screws (Rapid 51-3341)
- Die-cast box, 115 × 90 × 55mm Eddystone. Hammond 120 × 100 × 60mm Rapid 30-7070.
- Thermal cut-out SetFuse X1 (Rapid 26-0940 (127°C) or 26-0900 (105°C))
- TO220 clip-on heatsink
- Rubber grommet for enclosure cables exit hole (Rapid 04-0202)


Mains input
L
N
E
Thermal cutout
Primary
T1
Secondary
17V AC
R1
C1
C2
C3
C4
C5
C6
C7
C8
C9
D1
D2
D3
D4
D5
D6
D7
D8
D9
D10
D11
D12
IC1
IC2
15V
C10
C11
C12
C13
25V
C14
C15
R2
R3
R4
R5
A
B
C
Pad 4
Pad 5
Pad 6
Pad 7
Pad 8
Pad 9
Pad 10
Pad 11
+9V
0V
+15V
0V

*For Theremin link earth pads B-B

Fig.23. Standard low-noise Theremin +9/+15V power supply for the circuit in Fig.22. Note earth link B is linked.

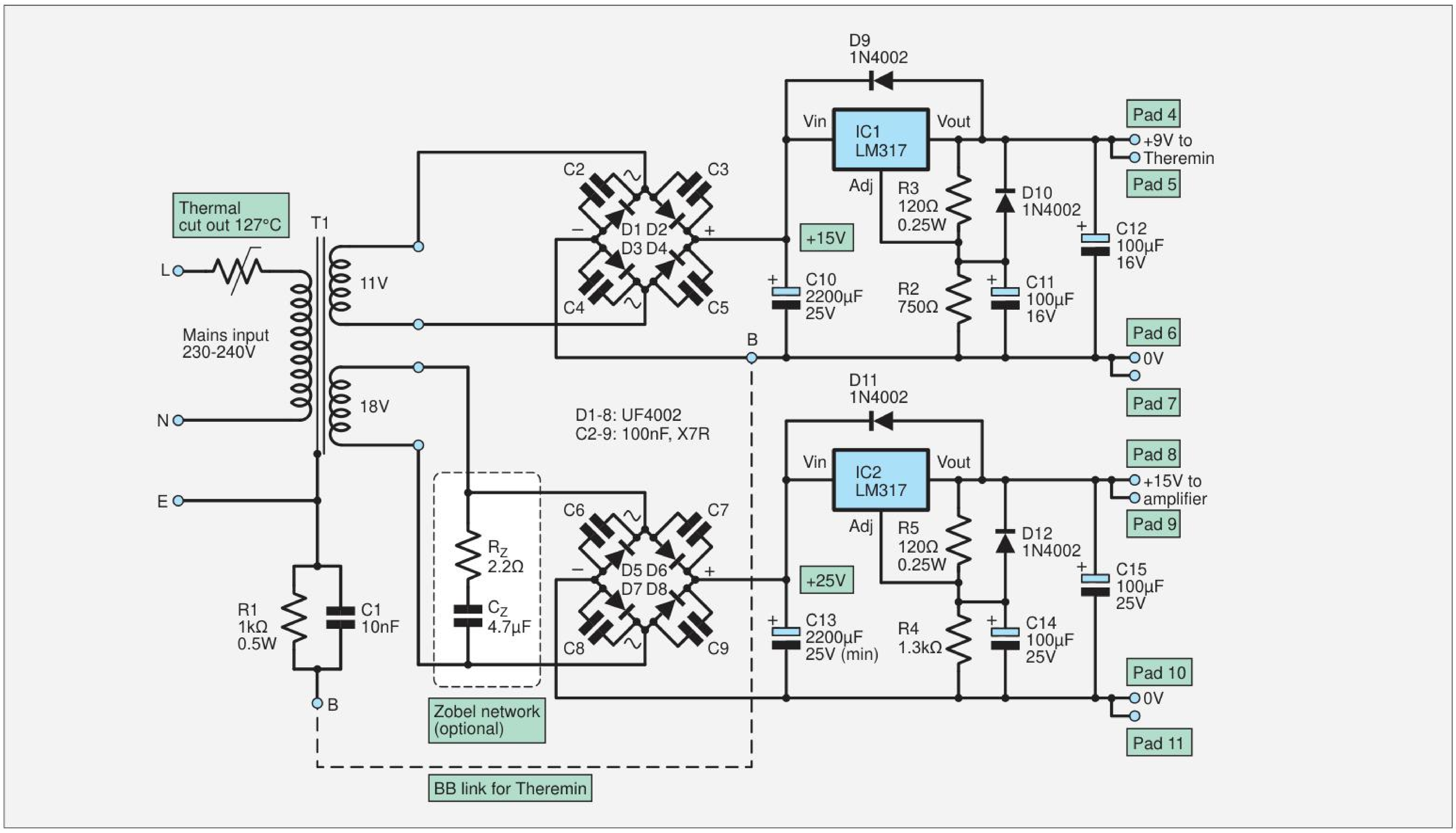

Thermal cut out 127°C
T1
L
N
E
Mains input 230-240V
11V
18V
R1 1kΩ 0.5W
C1 10nF
B
C2
C3
C4
C5
D1 D2 D3 D4
C6
C7
C8
C9
D5 D6 D7 D8
D1-8: UF4002
C2-9: 100nF, X7R
R_Z 2.2Ω
C_Z 4.7µF
Zobel network (optional)
BB link for Theremin
D9 1N4002
IC1 LM317
Vin
Vout
Adj
R3 120Ω 0.25W
R2 750Ω
+15V
C10 2200µF 25V
D10 1N4002
C11 100µF 16V
C12 100µF 16V
Pad 4
Pad 5
+9V to Theremin
Pad 6
0V
Pad 7
D11 1N4002
IC2 LM317
R5 120Ω 0.25W
R4 1.3kΩ
+25V
C13 2200µF 25V (min)
D12 1N4002
C14 100µF 25V
C15 100µF 25V
Pad 8
Pad 9
+15V to amplifier
Pad 10
0V
Pad 11

Fig.22. Full circuit diagram of the power supply with the Zobel add-ons in red. +9V and + 15 dual power supply for Theremin. By changing the links and values of R2 and R4 to 1kΩ this can be made into a ±12V supply for op amp circuits (see Fig.27).

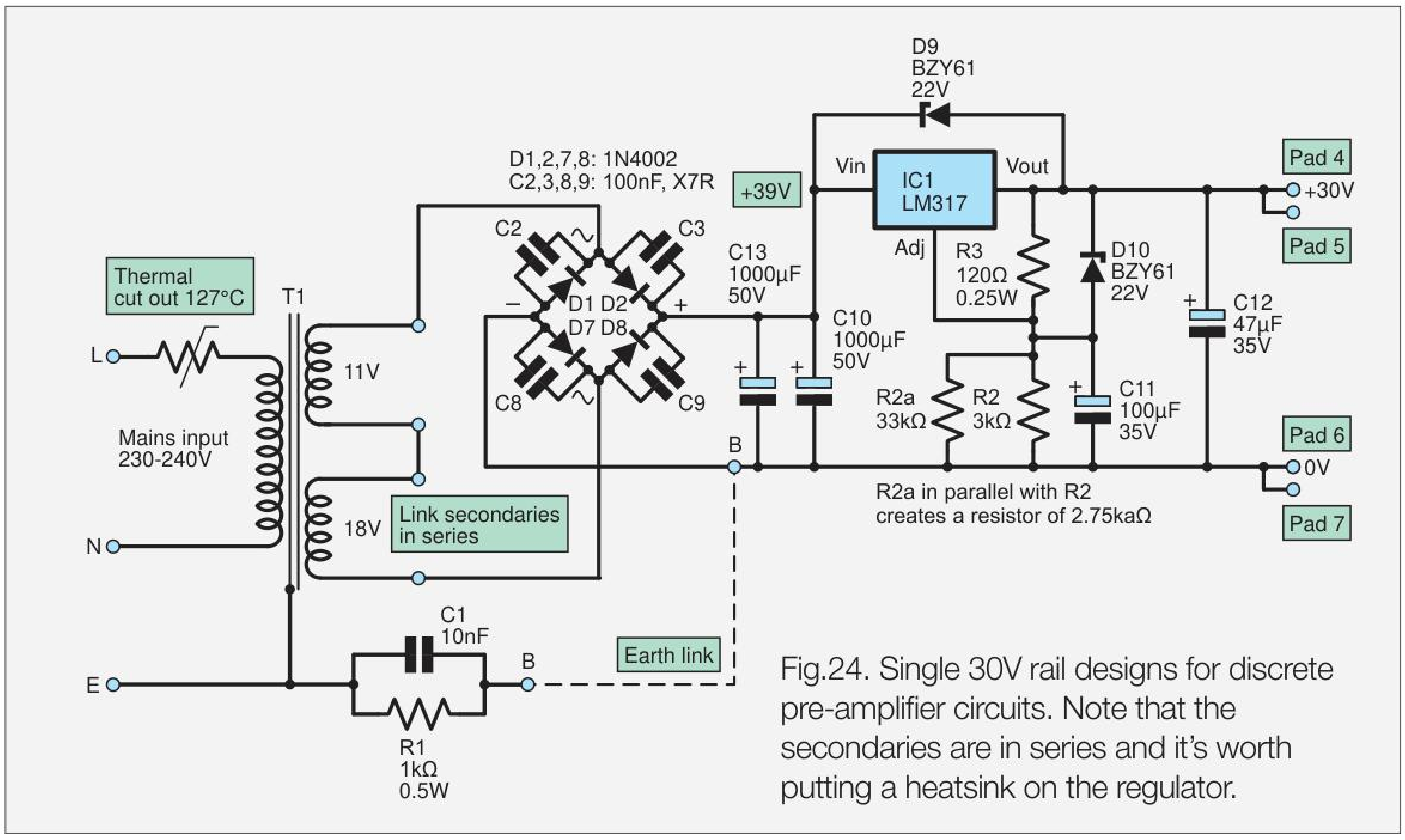

D9
BZY61
22V
D1,2,7,8: 1N4002
C2,3,8,9: 100nF, X7R
+39V
Vin
IC1
LM317
Vout
Adj
Pad 4
+30V
Pad 5
Thermal cut out 127°C
T1
C2
C3
C13
1000µF
50V
R3
120Ω
0.25W
D10
BZY61
22V
C12
47µF
35V
L
–
+
D1 D2
D7 D8
C10
1000µF
50V
11V
Mains input
230-240V
C8
C9
R2a
33kΩ
R2
3kΩ
C11
100µF
35V
B
Pad 6
0V
R2a in parallel with R2 creates a resistor of 2.75kaΩ
Pad 7
N
18V
Link secondaries in series
C1
10nF
E
B
Earth link
R1
1kΩ
0.5W

Fig.24. Single 30V rail designs for discrete pre-amplifier circuits. Note that the secondaries are in series and it's worth putting a heatsink on the regulator.

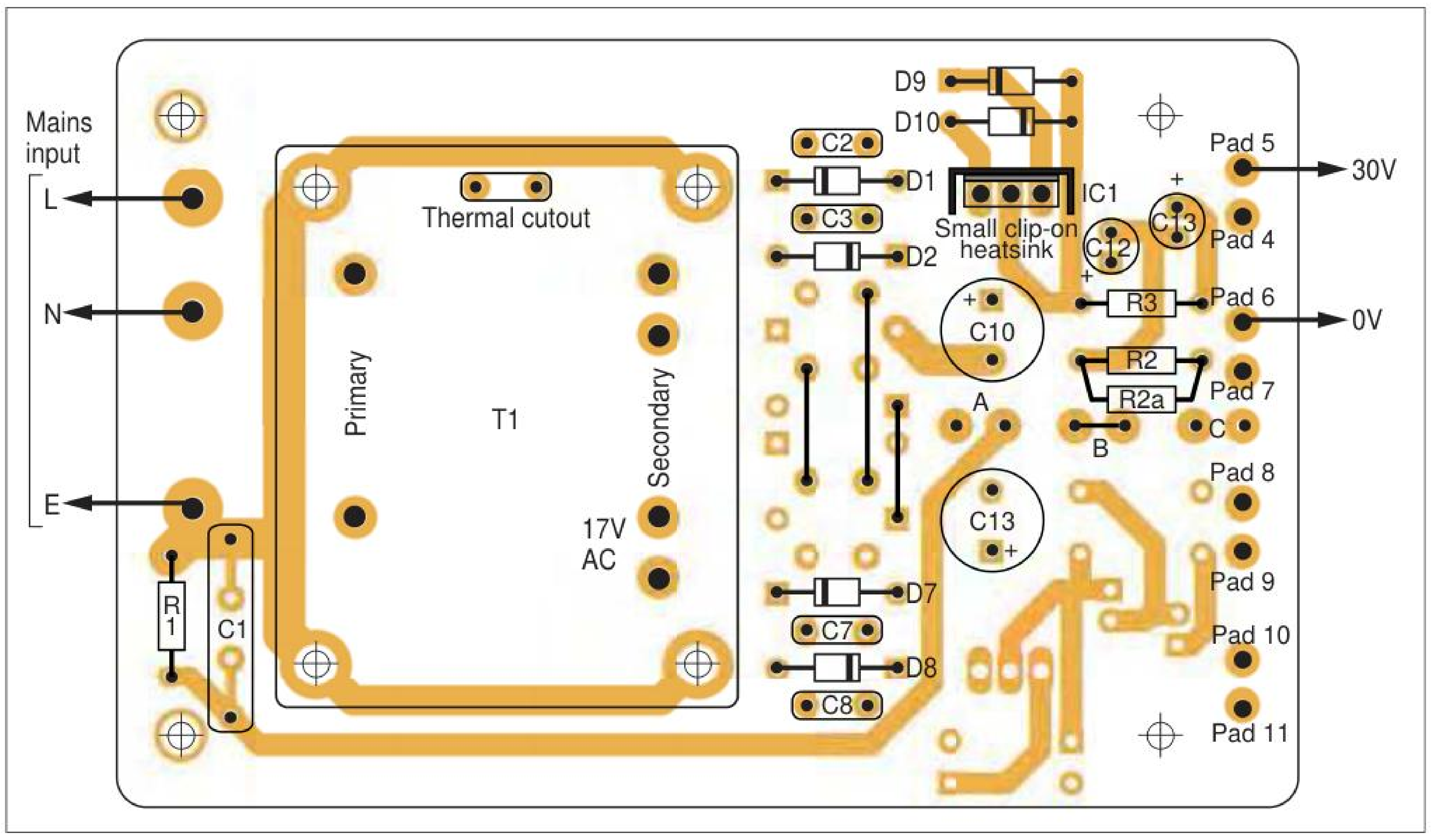

Mains input
L
N
E
Thermal cutout
Primary
T1
Secondary
17V AC
R1
C1
D9
D10
C2
D1
C3
D2
IC1
Small clip-on heatsink
C12
C13
C10
A
R3
R2
R2a
B
C
C13
D7
C7
D8
C8
Pad 5
30V
Pad 4
Pad 6
0V
Pad 7
Pad 8
Pad 9
Pad 10
Pad 11

Fig.25. Low-noise, single-rail +30V power supply. Very handy for single-rail preamplifiers using discrete circuitry. Note the three links to the left of C10/13.

Transformer and PCB
These can be obtained from the *PE PCB Service*. Other parts are available from the author.
jacob.rothman@hotmail.com
01597 829102

Power supply connectors
The mains input socket is pretty much standard, thanks to the IEC (International Electrical Commission). However, for the output connectors, prepare to enter a standardisation minefield, it's complete chaos. You can use screw terminals, 4-pin male XLR sockets, terminal blocks or one of the huge range of so-called DC connectors with an outer and centre pin.

One so-called 'standard' in the audio industry for guitar pedals is a 2.1mm DC connector wired centre pin negative. Another 'standard' is polarised the cable. Normally, figure-of-eight thin speaker cable is used with the rib or printed line denoting positive. This can be seen coming out of the protective rubber grommet in Fig.21.

Variations

There are four variants of the power supply using the same board. This was originally designed for the *PE Theremin*, but with simple variations can be used to power a multitude of audio circuits.

1) **+9V and +15V dual-rail** – this is the 'standard dual-rail power supply shown in Fig.22 It is designed to power a Theremin and its associated amplifier driving the speaker. If the amplifier is not used, then the 15V power supply can be omitted and the circuit simply becomes a low-noise +9V supply.
2) **Single-rail +30V** – higher voltage design for discrete pre-amps and single rail op amp circuitry, as shown in Fig.24
3) **±12V general-purpose dual-rail** –ideal for low-power op amp applications such as pre-amps and musical synthesisers. Shown in Fig.27.
4) **Positive-earth –9V** – designed for germanium circuits, such as Tonebender fuzz pedals and old 1960s radios, typically those made by Roberts and Bush. This is a nice little extra I thought up after the Theremin supply was designed, built and finished. We haven't got space to cover it this month, so it will be described in the next column.

Links on the PCB

On the PCB overlay there are three link positions A, B and C, as shown in Fig.23 These are needed to connect the power supply DC ground or 0V to the ground lifted (by R1 and C1) mains earth connection. Link A connects the 0V of the 17V AC secondary winding power supply rail to mains earth. Link B connects the mains earth to the 11V-AC-fed power supply rail 0V line. Link C connects the positive of the 17V fed supply to the 0V of the 11V fed supply. This is used to make centre-tapped dual rail supplies.
Note that when using the Theremin +9/+15V power supply the mains earth is connected to the 0V of the 9V supply. This is because the Theremin needs a stable earth reference – more so than the amplifier.

Capacitor 'tuning'

Since voltage regulators are a negative-feedback control system with a falling open-loop gain at high frequencies, the reduction in output impedance becomes less effective at high frequencies. This means the output impedance of linear voltage regulators is slightly inductive. This can cause a resonant noise peak with the output capacitor (C12) if it is a low ESR (around 0.1Ω) type. National Semiconductor application engineer Robert Pease showed in his book *Troubleshooting Analogue Circuits*, that a bit of loss in the output capacitor was necessary. An ESR of 0.6Ω to 3Ω was needed to avoid noise peaks. (To see the noise

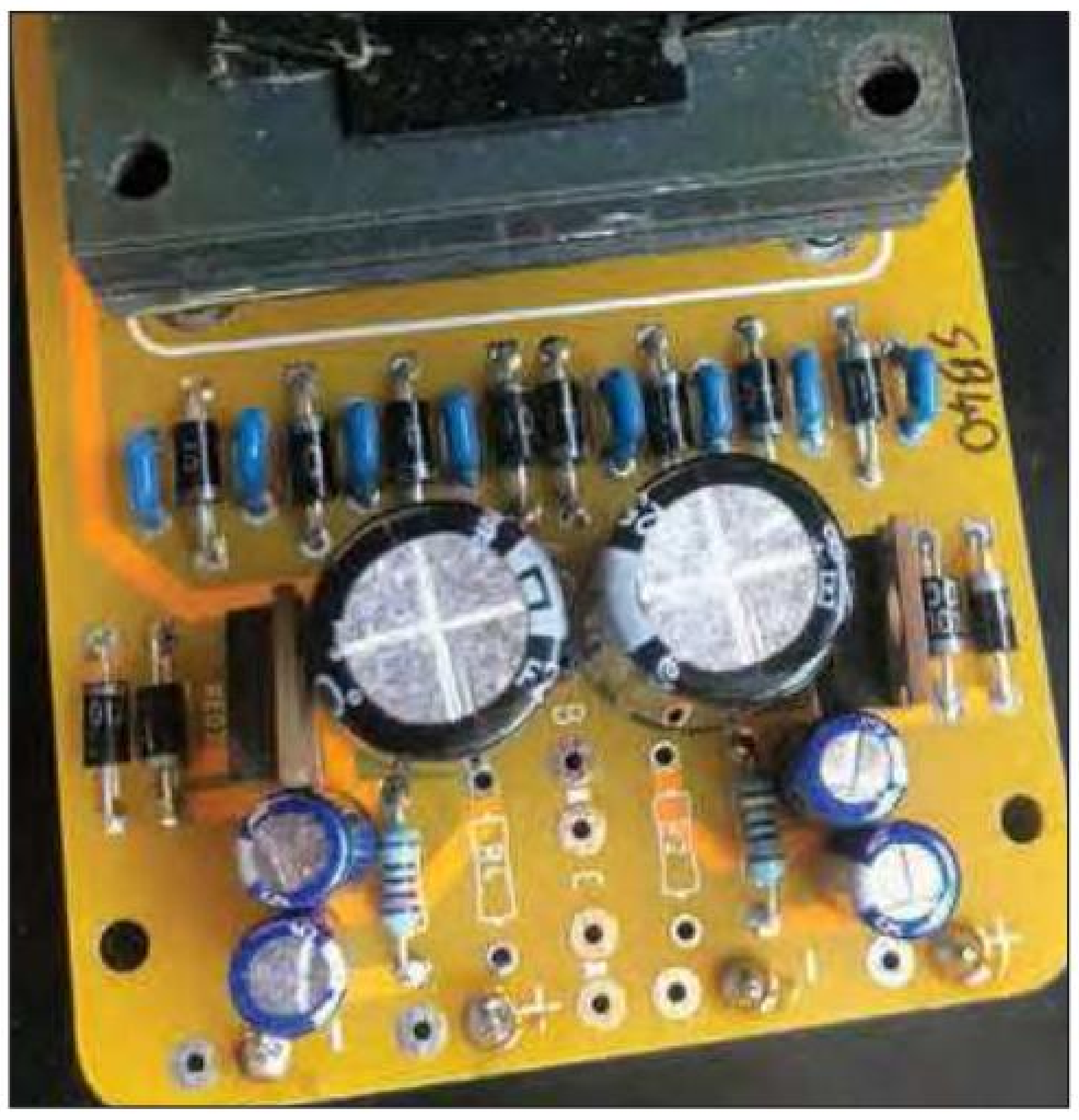
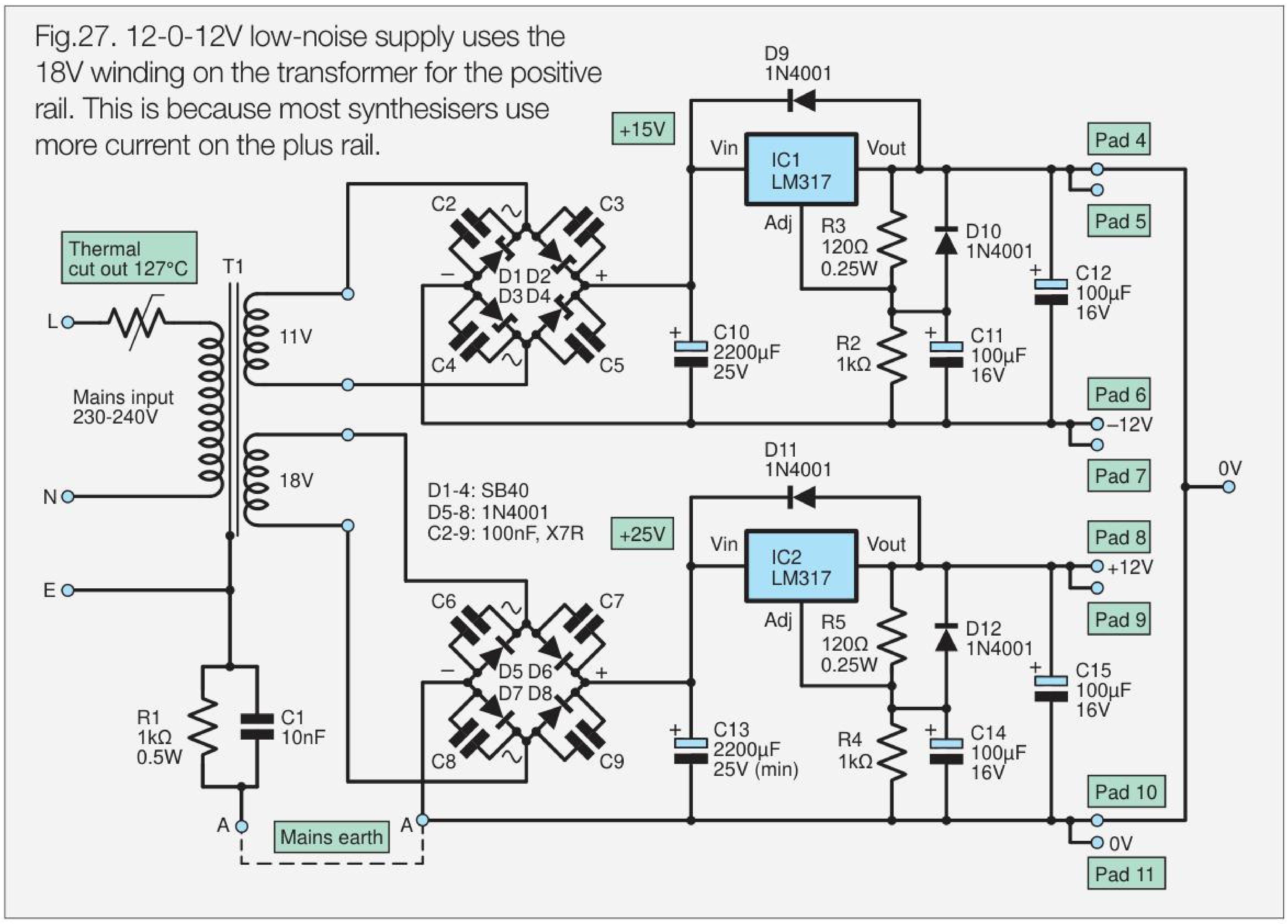
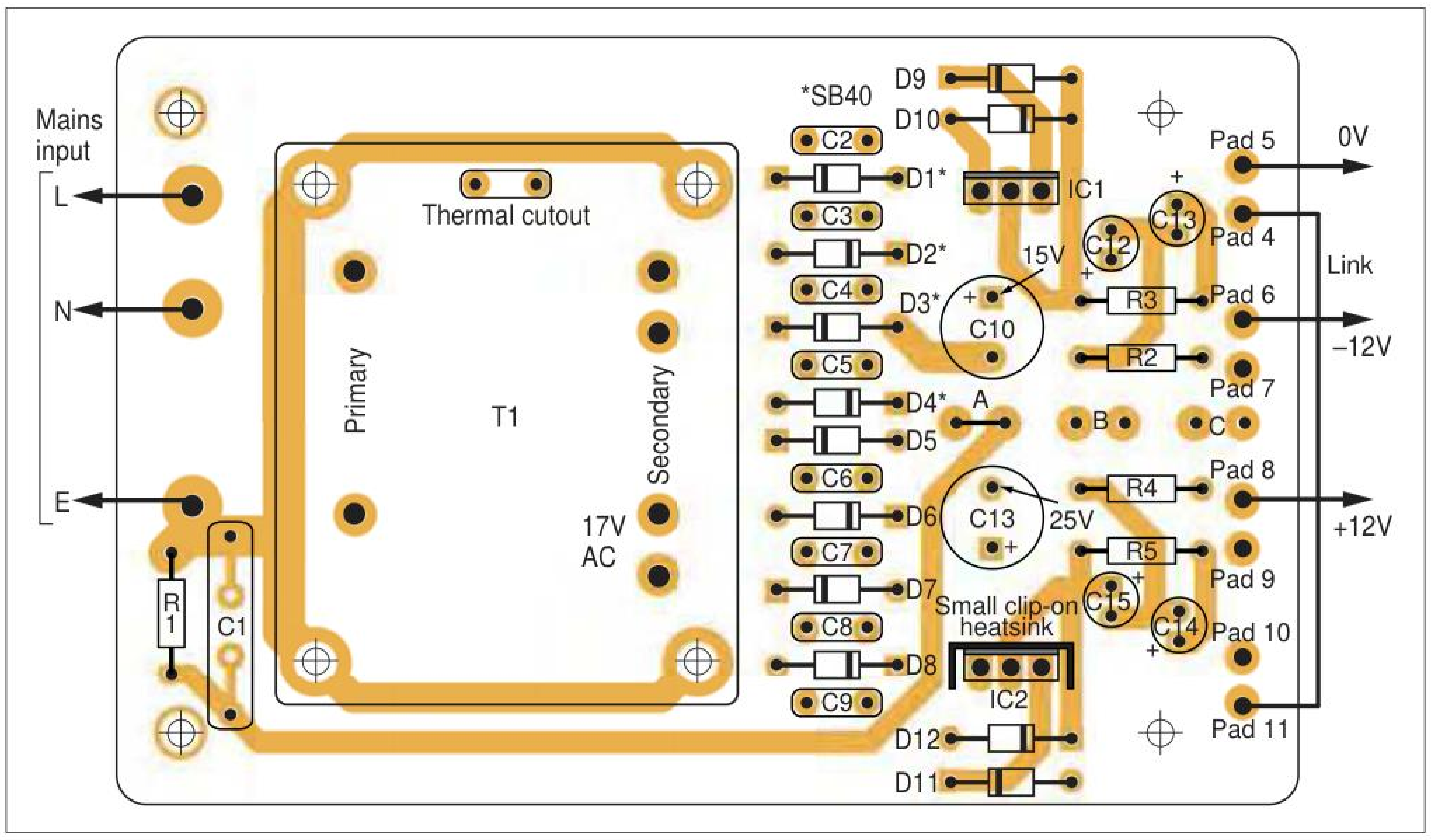


Fig.26. Basic board before final voltage setting resistors R2 and R4 are added. Note the blue snubber capacitors across the rectifiers.

Fig.27. 12-0-12V low-noise supply uses the 18V winding on the transformer for the positive rail. This is because most synthesisers use more current on the plus rail.



D9
1N4001
+15V
Vin
IC1
LM317
Vout
Pad 4
Pad 5
C2
C3
Adj
R3
120Ω
0.25W
D10
1N4001
Thermal cut out 127°C
T1
D1 D2
D3 D4
C12
100µF
16V
L
11V
C10
2200µF
25V
R2
1kΩ
C11
100µF
16V
C4
C5
Mains input 230-240V
Pad 6
–12V
D11
1N4001
Pad 7
0V
N
18V
D1-4: SB40
D5-8: 1N4004
C2-9: 100nF, X7R
+25V
Vin
IC2
LM317
Vout
Pad 8
+12V
E
C6
C7
Adj
R5
120Ω
0.25W
D12
1N4001
Pad 9
D5 D6
D7 D8
C15
100µF
16V
R1
1kΩ
0.5W
C1
10nF
C13
2200µF
25V (min)
R4
1kΩ
C14
100µF
16V
C8
C9
Pad 10
A
Mains earth
A
0V
Pad 11



Mains input
L
N
E
R1
C1
Thermal cutout
Primary
T1
Secondary
17V AC
*SB40
C2
D1*
C3
D2*
C4
D3*
C5
D4*
D5
C6
D6
C7
D7
C8
D8
C9
D9
D10
IC1
15V
C12
C13
C10
R3
R2
A
B
C
C13
25V
R4
R5
C15
C14
Small clip-on heatsink
IC2
D12
D11
Pad 5
0V
Pad 4
Link
Pad 6
–12V
Pad 7
Pad 8
+12V
Pad 9
Pad 10
Pad 11

Fig.28. Low-noise, dual-rail 12-0-12V power supply. A useful general-purpose supply – handy for op amp circuits. Note the link from Pad 4 to Pad 11, and the A link.

effect more clearly, disconnect the adjust pin decoupler capacitor C11). A link to the original 1989 article by E Dietz is here: **https://bit.ly/pe-aug20-dietz**

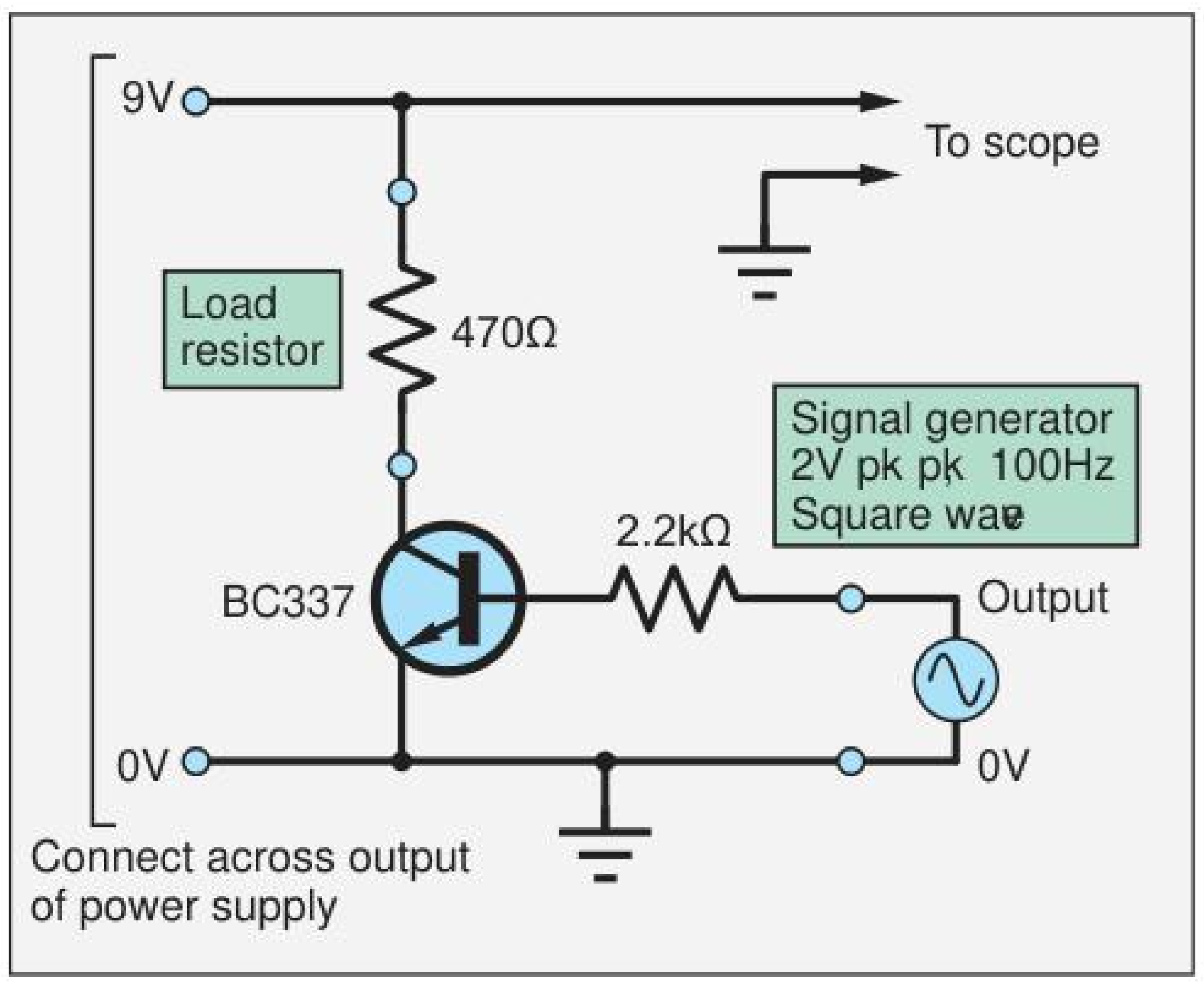
Making C12 a large value, say 470µF, will swamp this noise problem, but then another problem emerges in that a lower frequency ringing of a few cycles (around 80mV pk-pk) can occur if the regulator load is switched on and off. This is because too big a capacitor across the output reduces the open-loop gain of the whole system, causing ringing as the negative-feedback loop seeks to correct its self in a sluggish manner, then overshooting. This effect is proportional to load current. Again, a damping resistance in series with the capacitor can reduce this problem.

Switched-load testing

The way to test for poor dynamic load response is to put a 'scope probe set to AC on the output and dab a load on and off. A better way, is to electronically switch the load on and off with a transistor, such as the circuit shown in Fig.28. By driving the transistor with a square wave from a signal generator at around 100Hz the sweep of the 'scope can be synchronised to get a good view.

By using these techniques I was able to get the noise down to 0.8mV peak-to peak. An output capacitor (C12/15) of around 47µF to 100µF with an ESR of around 1Ω works, and is cost-effective for both problems. A cheap wet electrolytic could be used, but this will have a short life. A good solution is a manganese dioxide (MnO_2) solid-aluminium (SAL) 123 series capacitor (ESR typically 1.3Ω) but these stopped being made in 2015. This is shown in Fig.29. National Semiconductor used to recommend tantalum beads, but they don't like surges due to shorting during testing and powering up. In military work, special metal-cased surge-resistant tantalums are used, but they cost serious money. The new organic polymer SAL types have too low an ESR. The best noise results I've had so far have been with a Nichicon 470µF 16V RNE1C471MDN (ESR = 0.01Ω) in series with 0.56Ω resistor, this giving a more accurately defined total ESR which can be a variable capacitor parameter.

The adjust pin filtering capacitor (C11/14) can have a quite high ESR before it becomes ineffective, up to around 20Ω. I use a tantalum capacitor with a 10Ω series resistor to protect from surges. A value of 4.7



9V
To scope
Load resistor
470Ω
Signal generator
2V pk pk 100Hz
Square wae
2.2kΩ
BC337
Output
0V
0V
Connect across output of power supply

Fig.28. Switched load for power supply transient-response testing.

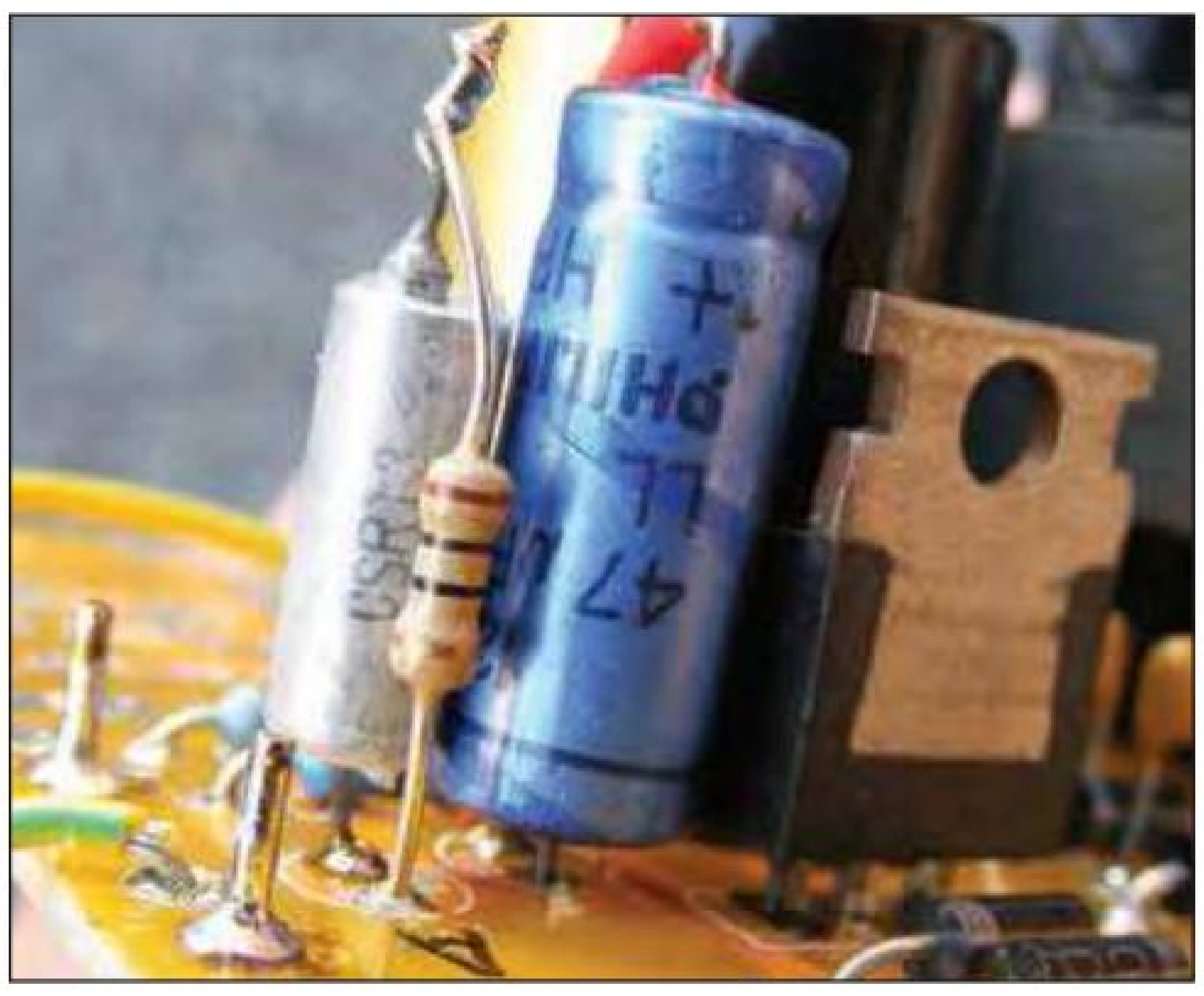


Fig.29. The blue capacitor is a solid-aluminium manganese dioxide (MnO_2) Philips output capacitor (C12). This has a relatively high and consistent ESR, which gives a stable response in response to changing loads. The silver-coloured metal-cased tantalum capacitor has a series resistor to increase reliability. (Note these photos are of the positive earth –9V PCB, which is covered next month).

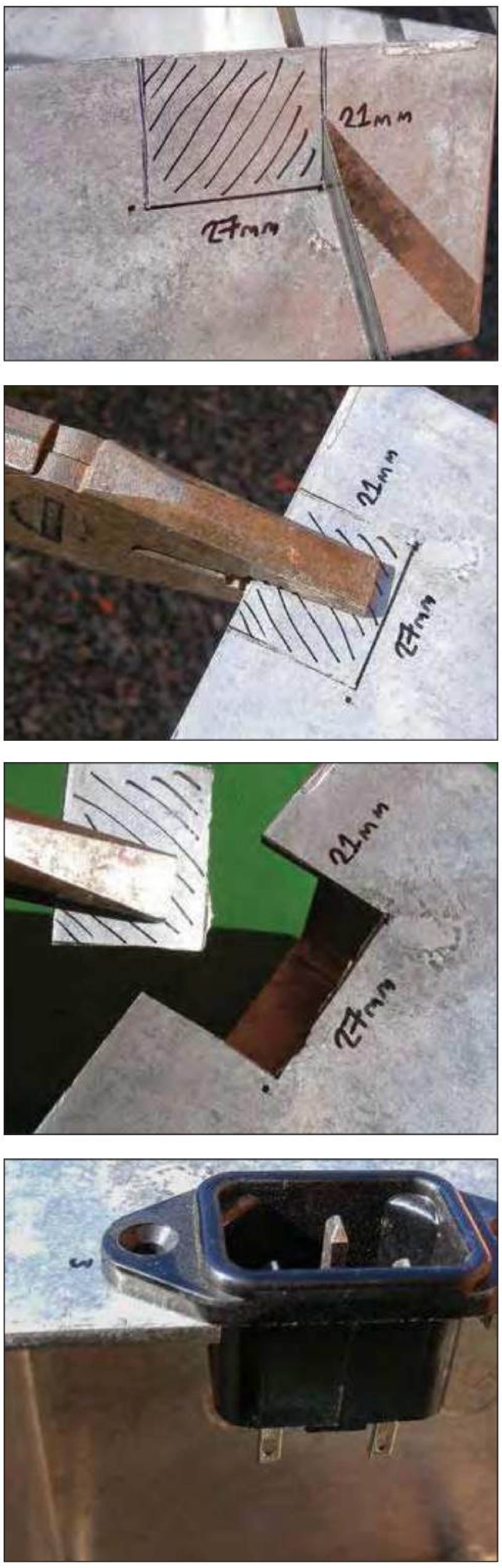


Fig.30. Stages in cutting the hole for mains IEC socket in die-cast box (top to bottom):

a) Mark out area to be removed and cut down the two vertical sides with hack saw.
b) Grip 'tab' firmly with pliers
c) Snap off 'tab' with pliers.
d) Position the socket to mark out the screw holes.

to 22µF works fine – see Fig.29. A polymer SAL capacitor works effectively as well. A diode (D10,D12) is used to protect the regulator adjust pin from discharge on turn off or output shorting. In the current-limited tantalum circuit, a 1N4148 is sufficient. If no resistor is used, a 1N4001 is needed, as previously specified.

Construction

Although it's tempting just to solder the transformer to the PCB, that's not strong enough mechanically; it needs to be bolted down. I've had pieces of equipment where the transformer has sheared off the PCB when dropped. It's not good having a lump of steel loose inside the box! Remember to employ the standard electronic construction technique of soldering after bolting, to the prevent the soldered joints being strained. A suggested mounting arrangement is shown in Fig.1, *Part 1,* where 3mm bolts are used. The core is also earthed by the bolts, essential to ensure safe operation of the thermal cut-out. Incidentally, it's a good idea to use a smear of heatsink compound to aid thermal coupling between the thermal cut-out and the transformer core. This should be pressed firmly against the core prior to soldering. (see Fig.20). Remember to solder it quickly, otherwise it may overheat and go open-circuit!

Testing

The first thing to do is to make it safe to turn on. There is mains voltage on the board; if you are not scared of it, you should be. I always tape over exposed tracks and insulate terminals with silicon rubber sleeves. I also put a rubber boot over the mains input connector. Check there is earthing continuity from the earth pin on the plug to metal box. If there is no continuity you could be electrocuted.

When turning on, listen for any buzzing noises from a stressed transformer or odd cracks and hisses from incorrectly inserted electrolytic capacitors swelling up. I know it sounds paranoid, but I've been on the receiving end of exploding electrolytic capacitors from inexperienced students, so I insist on them wearing glasses. If it passes this test, switch off and feel for any hot components. If okay, switch on again and measure the output voltage. Next, put on a suitable load resistor to give the maximum current draw required. This will normally be a big high-wattage type and will get hot. For example, if you are making a 12V power supply and need a 100mA output, then use a 120Ω 2W resistor. Finally, while loaded, check components for excessive heating. Note, it may take about 30 minutes for the transformer to reach its full running temperature. At this point it's worth checking the electrical noise level.

On the case

Electronics belongs in metal boxes. They provide electrical safety when earthed, electromagnetic fields are screened, heat can get out without ventilation holes, they can't catch fire and they don't fall apart after two years. After a good 30 years life they can then be effectively recycled, like all metals. Steel is more effective than aluminium alloys at reducing magnetic fields, but it is harder to drill and it can buzz mechanically if the transformer is too close to any of the panels.

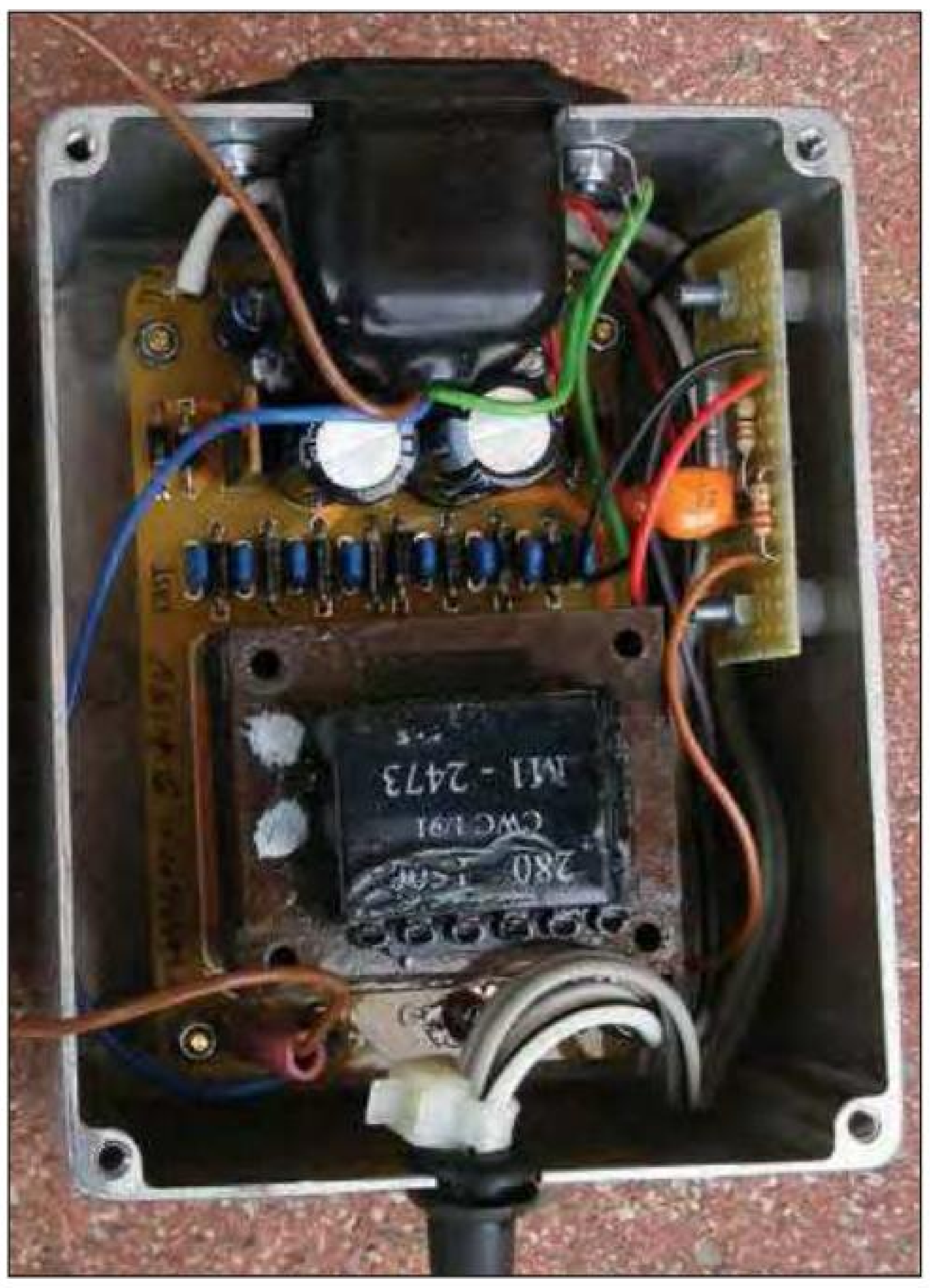


Fig.31. Interior of power supply – the small board on the side is the Zobel – the 'wacky circuit' from *Part 1*.

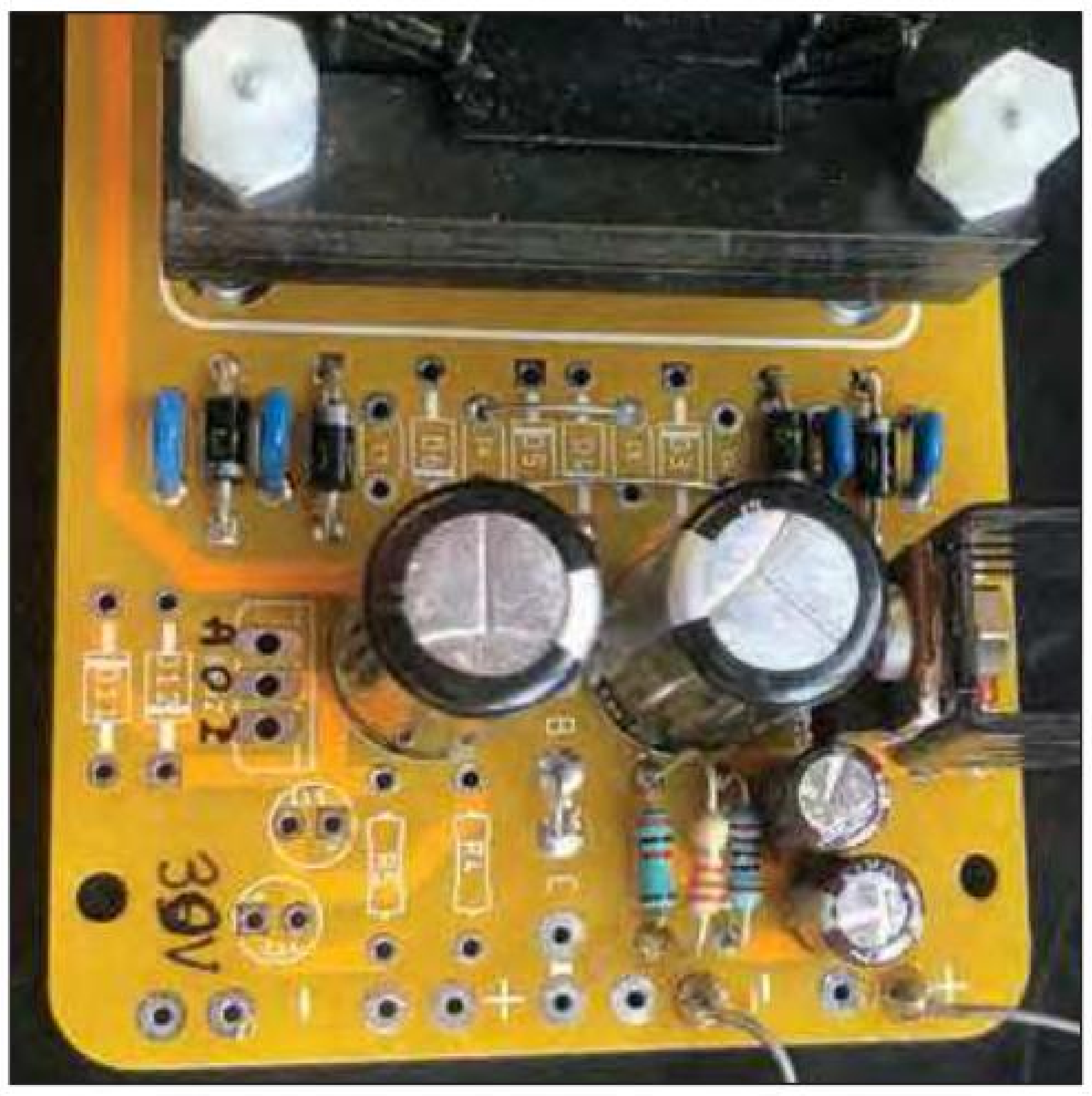


Fig.32. A view of the 30V board; note the links on the diode section and the regulator heatsink.

Socket mounting

The round DC connectors are relatively easy to mount with a 12.5mm (half-inch) hole. It should really have an anti-rotation flat on it but this needs a £400 metal punch set-up. It can be quite difficult cutting a rectangular hole in a metal box for the IEC socket. However, here's a little technician's trick I've used over the years to make it easier. It works very quickly with die-cast boxes, which although they are expensive, have always been the best choice for hand-built electronics. The stages involved are shown in Fig.30. The interior of the case is shown in Fig.31. The 30V board is shown in Fig.32.

I have loads of these power supplies in my studio and they are not humming along nicely like the wall-warts used to.

Next month

In the next issue we will finish this power supply project with a handy positive-earth –9V variant.

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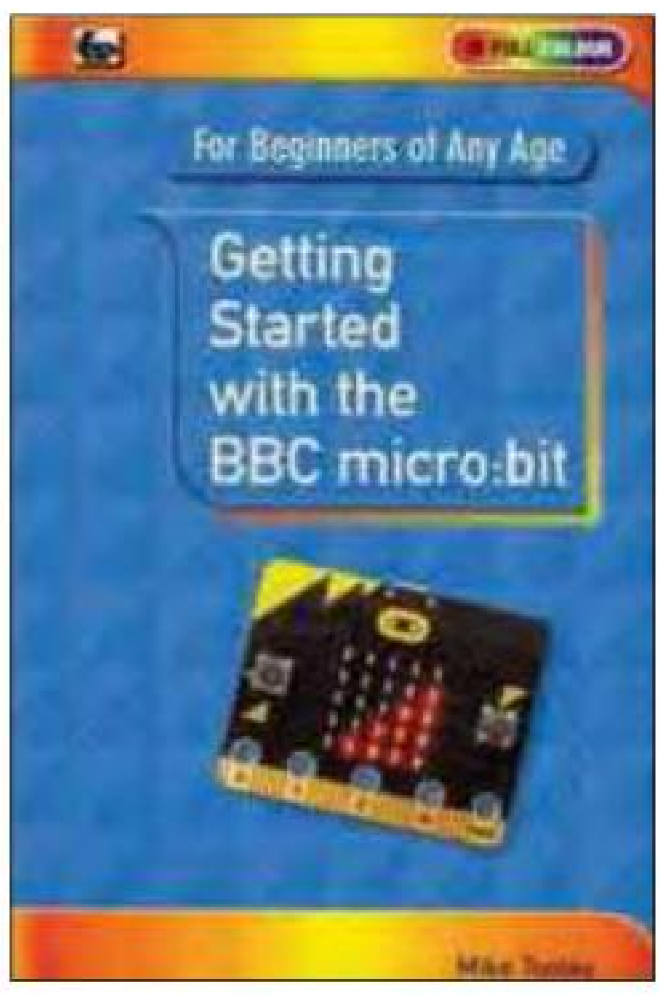

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Mike Tooley

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PEAK electronic design ltd
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Slope R=53Ω
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on - test
scroll - off
warning: not for in-circuit

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LCR and impedance meter
PEAK electronic design
Inductor 0.310%
L=701.1µH 15kHz
LCR45
on - menu
enter - off
warning: avoid charge/voltages
Complex Impedance
Impedance 200kHz
+25.6 +j155.1Ω

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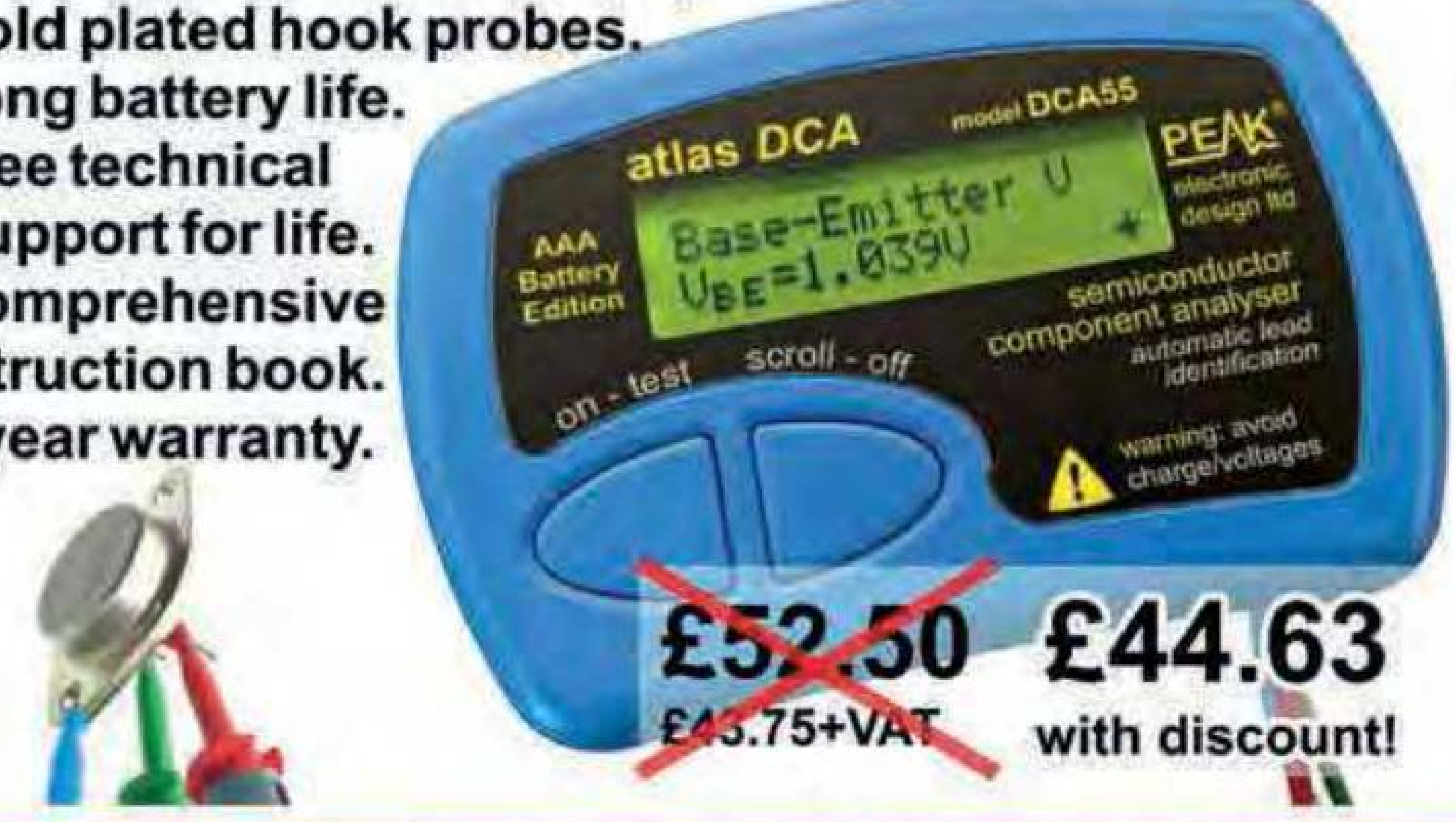
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model DCA55
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VBE=1.039V
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ESR, low resistance and capacitance meter
+ Audible Alerts
with automatic discharge function
on - test
off

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